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AMERICAN AMPHICŒLIAN CROCODILES

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As long ago as 1849, Sir Richard Owen described[1] a genus (*Hyposaurus*) of amphicœlian crocodiles from the Cretaceous of New Jersey, based upon imperfect anterior dorsal vertebræ, whose chief characteristic was the unusual development of the hypapophyses. But little has been added to our positive knowledge of the genus since its original description, though the remains of such animals are said to be common in the New Jersey deposits. Leidy, in 1865, described and figured[2] other vertebræ, and also assigned to the same genus certain fragments of hollow propodial bones. Cope, in 1869, also described[3] additional vertebræ and limb bones, with illustrations, but I think there is much uncertainty as to the correlation of these limb bones with the vertebræ. He also mentioned certain parts of the skull, from which it would appear that Owen was correct in locating his genus among the longirostres. However, Cope at the same time referred portions of the rostrum of one specimen from the same horizon and same locality as those of the specimens which he referred to *Hyposaurus rogersi* Owen, to a distinct species, under the name *Hyposaurus fraterculus*, but which he afterward removed[4] to the genus

[1] Owen, *Quarterly Journal of the Geological Society*, Vol. V (1849), p. 383.

[2] Leidy, *Cretaceous Reptiles*, p. 18, Plate III, Figs. 4, 16–21; Plate IV, Figs. 1–12.

[3] Cope, *Extinct Batrachia*, etc. (1869), p. 80, Plate IV, Figs. 10, 11.

[4] Cope, *Cretaceous Vertebrata* (1875), p. 254; *Proceedings of the Academy of Natural Sciences*, Philadelphia, 1875, p. 19.

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Gavialis, where it remains to the present time, though doubtless belonging in one or another of the tomistomid genera which have been described from the New Jersey deposits, if not really a *Hyposaurus*, as Cope first believed.

Leidy founded the genus and species *Thoracosaurus grandis* upon dermal plates from the same horizon.[1] He later assigned to the same species,[2] under the name *Thoracosaurus neocesariensis* De Kay,[3] an excellent skull, unassociated with other bones. I have read attentively Leidy's descriptions and remarks, as also those of Cope, concerning this and other specimens referable to this species, and nowhere do I find a positive collocation of the type with procœlous vertebræ, though Leidy assigned to the species the procœlous vertebræ previously described by Owen as *Crocodilus basifissus*.[4] It is probable, however, that *Thoracosaurus* is really a procœlian crocodile, since *Holops* Cope, a nearly allied, if not identical, genus, has been definitely associated with procœlous vertebræ.[5] Furthermore, Koken referred to the same genus,[6] though with some hesitancy, a skull from the Maastrichtian of northern Germany, which he identified specifically with *Thoracosaurus macrorhynchus* (Blaineville) Leidy,[7] originally described from the Lower Eocene of Germany. This geographical distribution is not at all remarkable, since we know that the genus *Mosasaurus* has a like distribution in the Maastrichtian of Belgium and the Cretaceous of New Jersey, as also the Pierre of the interior. We may, therefore, accept both *Thoracosaurus* and *Holops* as procœlian crocodiles, though further information as to the skeletal structure of each is highly desirable.

As to the third genus of crocodiles reputed to be procœlian from the Cretaceous of New Jersey, *Bottosaurus* Agassiz,[8] I do not think

[1] Leidy, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. VI (1852), p. 35.

[2] Leidy, *Cretaceous Reptiles* (1865), p. 5, Plates I–III.

[3] DeKay, *Zoology of New York*, Part III, p. 28, Plate XXII, Fig. 9 (*Gavialis*).

[4] Owen, *Quarterly Journal of the Geological Society*, Vol. V (1849), p. 381, Plate X, Figs. 1, 2.

[5] Cope, *Extinct Batrachia*, etc. (1865), p. 69, Plate I, Fig. 13.

[6] Koken, *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 754.

[7] Leidy, *Cretaceous Reptiles* (1865), p. 8.

[8] Agassiz, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. IV (1849), p. 169.

matters are as satisfactory. It is evident that the type species of the genus, *B. harlani* Meyer, is a broad-faced or brevirostrate form, but I do not feel so sure that it has procœlous vertebræ. Harlan based his species *Crocodilus macrorhynchus* Harlan (non-Blaineville) upon the larger part of the right mandible, which has been figured and more fully described by Leidy.[1] This mandible is very peculiar in lacking, apparently, the large foramen, so characteristic of all procœlian crocodiles, ancient and modern, and of the known amphicœlian forms, save certain species of *Goniopholis*[2] and other Goniopholididæ, such as *Pterosuchus*.[3] Indeed, the Parasuchia or Phytosauria, which I would exclude from the Crocodilia in the widest sense, have such a foramen. Cope later added another species, *B. tuberculatus*,[4] to the genus, but I fail to find any positive evidence of congenerousness with the type species, nor am I assured that the form is brachystomous even. *B. perrugosus* Cope, which may be the same as *Crocodilus humilis* Leidy, from the Laramie Cretaceous of eastern Colorado, was only provisionally referred to the genus.[5] A gigantic procœlian crocodile is not at all uncommon in the uppermost Cretaceous of the West, as mentioned by Hatcher and as I have seen from western Texas. No other evidence is forthcoming that *Bottosaurus* has procœlous vertebræ. If it really has, then an important fact has been for the most part overlooked hitherto, the presence of broad-faced crocodiles, with a short mandibular symphysis, from so low an horizon, forms which might stand in more immediate ancestral relationship with the modern Crocodilidæ than do any of the known Tomistomidæ (Rhynchosuchidæ) of the Cretaceous. I cannot resist the suspicion that *Bottosaurus* will eventually be found to be an amphicœlian form. It is a remarkable fact, as Koken has shown,[6] that the early longirostrate procœlian crocodiles are scarcely distinguishable generically, save in their vertebræ, from their contemporary longirostrate amphicœlian forms, and it is

[1] Leidy, *Cretaceous Reptiles* (1865), p. 2, Plate IV, Figs. 19–23.

[2] Owen, *British Fossil Reptiles*, Vol. I, p. 64 *t*, Plate XLII, Fig. 2.

[3] Owen, *Fossil Reptiles of the Wealden Formation* (1878), Supplement VIII, p. 10.

[4] Cope, *Extinct Batrachia*, etc. (1865), p. 230.

[5] Cope, *Cretaceous Vertebrata* (1875), p. 68, Plate VI, Figs. 5–8.

[6] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 93.

altogether likely that a similar likeness existed in those early crocodilian times between the amphicœlian Bernissartidæ and such forms as *Bottosaurus* must have been if really procœlian. Marsh has stated, however, that there are several forms of amphicœlian crocodiles in the New Jersey deposits,[1] and has, indeed, named one of them *Hyposaurus ferox*.[2]

Whatever may be the real truth in the case, that the upper New Jersey Cretaceous rocks have yielded the remains of longirostrate amphicœlian crocodiles seems definitely determined from certain remarks made long ago by Professor Cope incidentally in his description of *Hyposaurus derbianus* from Brazil.[3] These remarks have been so completely overlooked by all other writers upon fossil crocodiles, whether in textbooks or in technical papers, that I venture to quote them in entirety. Even Hay omitted reference to the paper in his remarkably complete catalogue of North American fossil vertebrates.

> The genus *Hyposaurus* has been hitherto represented by but one well-known species, the *H. rodgersi* Owen, of the Greensand of the Cretaceous No. 5[4] of New Jersey. Specimens in my possession demonstrate that the genus *Hyposaurus* belongs to the Teleosauridæ of St. Hilaire. It differs from *Metriorhynchus* Meyer in the presence of distinct lachrymal bones, and in the relatively small size of the prefrontals. From *Teleosaurus* proper it differs in the robust size and vertical direction of the teeth. The orbits are vertical and the sagittal region is a keel. In the *H. rodgersi* the frontal bone is narrower than in any of the species figured or described by Deslongchamps. The palatal foramina extend forward to the line of the posterior maxillary teeth, and the anterior border is rounded, not acute as in most species of the family. The specimens are not sufficiently complete to enable me to state positively the generic distinction from *Steneosaurus*. In *Teleosaurus* the vertebral hypapophyses only appear on the first and second dorsal vertebræ, while, as Owen observes, they are present on many of the dorsals in *Hyposaurus*. This peculiarity, and the great contraction of the frontal bone, render it very probable that the genus is distinct from *Steneosaurus*, but the diagnostic character yet remains to be discovered.

If the genus is closely allied to the true species of *Steneosaurus*, then it is quite certain that *Hyposaurus* is a member of the Teleo-

[1] Marsh, *American Journal of Science*, Vol. XIV (1877), Sep. p. 14.

[2] Marsh, *Proceedings of the Academy of Natural Sciences*, Philadelphia, 1871. p. 104.

[3] Cope, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. XXIII; *Paleontological Bulletin*, No. 40 (1885).

[4] Doubtless the Manasquan Marls.

sauridæ in the narrow acceptation. But Cope mentions no species, and it is now known that certain species referred to *Steneosaurus*, especially *S. geoffroyi* Owen,[1] do not belong in this genus,[2] or family even, but rather with the Pholidosauridæ, possibly *Pholidosaurus*. The lateral orbits which Cope gives for *Hyposaurus* is not a teleosaurid character. *S. geoffroyi* has elongated nasals, quite different from those of *Teleosaurus* proper, and it is probable that *Hyposaurus* will be found to possess them also, as in *Teleorhinus* Osborn. It is interesting to observe, however, that *Hyposaurus derbianus* "sends upward [from the jugals] a postorbital branch, which is external as in other Teleosauridæ, and not internal as in the Crocodilidæ"—a strong teleosaurid character that would remove the species from the Pholidosauridæ.

The horizon of *H. derbianus* is given by Cope as the equivalent of the "Fox Hills," that is of the Fort Pierre,[3] and perhaps equivalent to the New Jersey deposits. The specimen was from the province of Pernambuco.

A second genus of longirostrate amphicœlian crocodiles, from an earlier horizon, has been recently described by Osborn[4] from the Benton Cretaceous of Montana. Osborn separates the genus from *Hyposaurus* by the lesser curvature of the propodial bones, but, as I have stated, it is somewhat doubtful whether we actually know the propodials of *Hyposaurus* sufficiently well to afford this information, if at all; and the author seemed unaware that the longirostrate, if not teleosaurid, character of *Hyposaurus* is established. (The bones figured by Leidy do not show the curvature.) He compares the genus with *Teleosaurus*, to which there seems to be little real relationship, but does not compare it with such forms as "*Steneosaurus*" *geoffroyi*, which has elongated nasals, or with *Pholidosaurus* (*Macrorhynchus*), to which it does appear to be allied. *Teleosaurus* has short nasals and upwardly directed orbits, bordered posteriorly by a rather stout, external rim of bone; *Pholidosaurus* has lateral orbits, as described by Cope for *Hyposaurus* and Osborn for *Teleorhinus*, and nasals

[1] Owen, *British Fossil Reptiles*, Vol. III, p. 144, Plate XVIII.

[2] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 91.

[3] Stanton and Hatcher, *Bulletin 257* (1905), United States Geological Survey, p. 66.

[4] Osborn, *Bulletin of the American Museum of Natural History*, Vol. XX (1904), p. 239.

extending to the premaxillaries or anterior nares as in *Teleorhinus*. The elongation of the nasals occurs also in other longirostres, like *Teleidosaurus*, etc., as well as in most of the brevirostrate amphicœlian forms, such as *Goniopholis*, *Nanosuchus*, *Notosuchus*, and *Petrosuchus*. In all, or nearly all, reptiles having a greatly elongated mandibular symphysis, the splenial takes part in the union, as in *Teleidosaurus*, *Hyposaurus*, and other longirostrate amphicœlians, the gavials, plesiosaurs, *Champsosaurus*, etc. Most of the other characters given by Osborn for *Teleorhinus* are of wider than generic application, save the antero-posterior compression of the teeth, which also occurs in other of the long-snouted amphicœlian forms. It is therefore difficult to interpret the affinities of his genus prior to a more complete description of the excellent material upon which it was based. I have scarcely a doubt, however, that it belongs with the Pholidosauridæ rather than the Teleosauridæ.

During the past season several specimens, more or less fragmentary, of longirostrate crocodiles, including the posterior part of two skulls, quite different from each other, and cervical vertebræ were obtained from the Hailey shales of western Wyoming, by the University of Chicago party. I was first inclined to locate their horizon in the Niobrara, because of the presence of a distinctly Niobraran genus of plesiosaurs, but a more careful study of the stratigraphy of the Benton convinces me that it belongs somewhere in the Carlyle formation. The skulls both agree in having very narrow parietals, very large supratemporal fenestræ, small laterotemporal vacuities, and large orbits. The upward process from the jugal seems, in one of the specimens at least, to be internal, as in the Pholidosauridæ. I cannot distinguish either of the species at present from *Hyposaurus*, though it is not impossible that one or the other may be *Teleorhinus browni* Osborn. From the lowermost part of the Benton, just above the Dakota, Mr. William Reed some years ago collected a longirostrate skull in Wyoming. It would seem, hence, that crocodile remains are widely distributed throughout the Benton of the Rocky Mountain region.

In 1872 Cope named,[1] and in a later work figured,[2] a single

[1] Cope, *Proceedings of the American Philosophical Society*, Vol. XII, p. 310.

[2] Cope, *Cretaceous Vertebrata* (1875), p. 52, Plate IX, Figs. 8, 8*d*.

vertebra from the supposed Benton Cretaceous of Kansas, which he referred to *Hyposaurus* under the specific name *H. vebbii* or *H. vebbianus*. The locality whence his type was obtained is such that its horizon can only be the upper part of the Lower Cretaceous. Cope believed at first that the form was longirostrate, and so indeed it may yet prove to be. Within recent years I have recognized various fragments of the skull and vertebræ of what are evidently brevirostrate crocodiles from what probably is the same horizon as that of the type of *H. vebbii*, in southern Kansas. Whether or not the form or forms which they represent are conspecific with *H. vebbii* remains to be proven, but there is no doubt of the occurrence of a brachystomous crocodile in the Comanche of Kansas.[1]

In 1878 Professor Cope described[2] from the Morrison beds of southern Colorado the vertebræ of a small amphicœlian crocodile under the name *Amphicotylus lucasii*. In 1888[3] he collocated with these vertebræ a skull and various other bones, from the examination of which he reached the conclusion that the genus is identical with *Goniopholis* Owen, confined, so far as known otherwise, to the Purbeck and Wealden of England, Belgium, and northern Germany. In September of 1877, a few months prior to the appearance of Cope's description of *A. lucasii*, Professor Marsh briefly described[4] a genus and species of brachystomous amphicœlian crocodiles from the Morrison beds of Morrison, Colo., under the name *Diplosaurus felix*. I doubt not that the genus is identical with *Amphicotylus*, and, in much probability, the species is also identical with that of Cope. Marsh, however, refused to accept the synonymy of *Goniopholis*, figuring his species, without comment, in 1896[5] under its original name *Diplosaurus felix*. He, however, never gave any characters to distinguish his genus, and his figure shows, it is seen, a marked resemblance to those of various species previously assigned to *Goniopholis*, and especially *G. simus* Owen.[6] I have very recently

[1] Williston, *University of Kansas Geological Survey*, Vol. IV (1898), p. 78; Vol. II (1878), p. 391.

[2] Cope, *Bulletin of the United States Geological Survey of the Territories*, Hayden.

[3] Cope, *American Naturalist*, Vol. XXII (1888), p. 1106.

[4] Marsh, *American Journal of Science*, Vol. XIV (1877), p. 254.

[5] Marsh, *ibid.*, Vol. II (1896), p. 61.

[6] Owen, *Fossil Reptiles of the Wealden and Purbeck Formations* (1878), Supplement VIII, Plate V.

examined the type specimen, and am more firmly convinced of its congenerousness with *Goniopholis*. We may, therefore, assume that both *Amphicotylus* and *Diplosaurus* are synonyms of *Goniopholis*, as did Zittel.[1]

Marsh has also referred to the genus *Diplosaurus* a fragment of a propodial bone discovered by him in 1868 in the Baptanodon beds of the Uinta Mountains.[2] Inasmuch as it must be almost, if not quite, impossible to determine with any degree of assurance the generic affinities of his species from such very incomplete material as he possessed, and as his specimen has never been described or figured in the slightest, the name *D. nanus* Marsh must be considered as purely *nomen nudum*. The specimen may be of a brevirostrate crocodile, but, considering the beds in which it was found, it is far more probable that it really belongs with a dolichostomous form.

Very recently Dr. W. J. Holland has described and figured[3] an excellent skull from the upper Morrison beds of Freeze Out Mountains, Wyoming, as *Goniopholis? gilmorei*. While the author was justified in assigning a new specific name to his specimen, he has given us no distinctive characters, nor was it possible for him to do so. The pitting of the superior surface of the skull is quite unknown in either *G. lucasi* or *G. felix*. The former species was, as we have seen, based exclusively upon vertebræ, and no description or figure has ever been given of any part of a skull presumably or definitely conspecific with the type. The type specimen of *G. felix* does not exhibit the superficial markings, though doubtless it will when fully extricated from its matrix, to which is yet adherent the thin exterior portion from which the major part of the skull has been removed.

Such pitting of the superior surface of the skull is quite characteristic of the genus *Goniopholis* and allied forms, and while it is possible that a close comparison of uninjured specimens might reveal specific characters, such is doubtful. The low parapet of bone bordering the posterior inner margin of the superior temporal

[1] Zittel, *Handbuch der Paleontologie* (1890), Vol. III, p. 676.

[2] Marsh, *American Journal of Science*, Vol. XIV (1877), p. 346.

[3] Holland, *Annals of the Carnegie Museum*, Vol. III (1905), p. 431.

vacuity on the parietal and "mastoid" bones is of doubtful specific value, as one, I think, will be assured from the comparison of different skulls of modern crocodiles.

The teeth, as figured by Dr. Holland, are not unlike those of *Goniopholis tenuidens* Owen.[1] That the specimen belongs in the genus *Goniopholis* I have little or no doubt—at least there appears to be less difference between our species and certain European ones, than between the known European species. No procœlous vertebræ have ever been found in the Morrison beds, nor indeed any from below the Upper Cretaceous in any part of the world, unless the vertebræ figured some years ago by Seeley from the English Wealden are truly crocodilian in nature.[2] I cannot agree with Dr. Holland in the belief that the arrangement of the bones on the under side of the cranium of his specimen is like that of the modern crocodiles. The under part is somewhat injured posteriorly, as stated by Dr. Holland, and as I can corroborate from an examination of this specimen, the whole of the false palate back of the maxillæ wanting. We have no reason to assume, however, that the structure here differs materially from that of the Goniopholididæ in the boundaries of the posterior nareal openings; if it does agree with the modern crocodiles in this respect, it would of course remove the form from the Goniopholididæ and substantiate another generic appellation.

Of the four specific names that have heretofore been given to the goniopholidids from America, the three based upon specimens from the Morrison beds may all be valid, and it is not at all improbable that they represent more than one species; but, so far, we have no conclusive evidence that such is the case.

I may add that crocodilian teeth are widely distributed in the upper Morrison horizons, as also in the Comanche deposits of western Kansas.

Coelosuchus reedii, genus and species new.

Recently I have received for examination, from the University of Wyoming, through its curator of paleontology, Mr. William Reed, the remains of a large amphicœlian crocodile, evidently of a brachy-

[1] Owen, *British Fossil Reptiles*, Vol. I, p. 642.

[2] Seeley, *Quarterly Journal of the Geological Society*, 1887, p. 212.

stomous form. They were collected during the past season by Mr. Reed in the vicinity of Wilcox, Wyo., in a dark shale of the Graneros division of the Benton, and below the heavily laminated shales which must be ascribed to the Mowrie beds of Darton. I have recognized what I believe to be the same horizon, also fossiliferous, two hundred miles or more to the northwest in Wyoming, lying below the laminated shales yielding numerous fish scales and fish bones. The Hailey shales lie some four hundred feet higher than this horizon, above the Mowrie shales, and above thin layers of limestone which may represent the Greenhorn limestones of Darton. Mr. Reed has traced the Wilcox fossiliferous horizon for about thirty miles into Carbon County on Troublesome Creek, where it also yields vertebrate fossils.

The fossils sent me are for the most part more or less fragmentary and water-worn. They include two or three species of plesiosaurs, one of which seems closely allied to *Trinacromerum anonymum* Williston, from the Benton of Kansas; various fragments of the carapace and plastron of a large, thick-shelled turtle; the spine of a shark, not unlike those of *Corax* from the Cretaceous of Kansas; small shark teeth; and a large premaxillary bone with a single long tooth, whose systematic position I have not yet determined.

I can distinguish but a single species, among the crocodilian remains preserved, though they differ greatly in size and may in reality be of different forms. Of course, none of the bones can be associated together as of one individual.

The ilium (Fig. 1) differs from that of a modern crocodile in the greater elongation of the posterior process, and in the relatively less width of the bone. An ischium (Fig. 5) of a smaller individual differs in the less expansion of the distal end, its more rounded posterior angle, and the greater obliquity of the shaft of the bone. The pubes of several individuals are represented by more or less fragmentary parts, all of about one size. One nearly complete specimen is shown in Fig. 2. It is also noticeable for the slenderness of the shaft, and the moderate dilatation of the distal extremity, differing markedly in this respect from the known forms of *Goniopholis* and *Bernissartia*. The upper extremity of a humerus of a large individual is shown in Fig. 3. Its curvature is slight, much less than of a humerus of nearly

equal size of a longirostrate form from the Hailey shales. Other smaller humeri are present, nearly complete. They are slender and nearly straight, the lower extremity scarcely differing from that of a modern alligator or crocodile. The distal end of a tibia and its distal face are shown in Figs. 6 and 7. The proximal and distal ends of two large coracoids are shown in the figure. I have outlined the connecting part between them as would seem natural. The distal extremity is also noticeable for its moderate expansion.

The numerous vertebræ preserved are of various sizes and from

FIG. 1.—*Coelosuchus reedii*. Right ilium, one-half natural size.

various places in the vertebral column. A cervical (Fig. 8) has its extremities almost amphiplatyan; the hypapophysis is small; the parapophysial articulations are not large and are situated near the end. The neurapophyses are attached by a loose suture. The length of the vertebra is 50 mm; its width, 44 mm. A dorsal centrum, of which the anterior articular surface is shown in Fig. 9, has a very smooth surface exteriorly, and is but gently concave longitudinally. The posterior central articular surface is nearly flat, the anterior rather deeply cupped. The length of the centrum is 59 mm; its width, 50 mm. Another centrum (Fig. 10) is much more compressed from side to side, presenting a vertically oval figure at the ends and in cross-section. This centrum has a length of 50 mm and a width of but 36 mm. The largest (dorsal) centrum preserved has a length of 65 mm and width of 70 mm.

Various fragments of the skull are preserved, but no teeth can be detected, though a fragment of a dentary or maxilla has numerous thecæ for their reception. The skull fragments are massive and deeply pitted, conclusively proving, it seems to me, the brachystomous nature of the face. The largest portion preserved is that figured herewith, the posterior part of the left mandible. It measures 155^{mm} in its greatest width, and resembles the corresponding part of the mandible of *Goniopholis tenuidens*, as figured by Owen.[1] If the skulls of the two species were of like proportions, the present must have measured over four feet in length. Species of *Goniopolis* have no mandibular foramen, so characteristic of the crocodiles, and its absence in the present species, together with the great width of the bone and its numerous deep pittings, indicates conclusively the brevirostrate character of the form. This is also indicated by the large size of the anterior extremities, the bones preserved showing that they were fully as large as the posterior ones, a character also seen in *Goniopholis* and *Bernissartia*, and very different from the small fore legs of the longirostrate types.

FIG. 2.—*Coelosuchus reedii*. Right pubis, one-half natural size.

The Goniopholididæ are supposed to have been denizens of fresh or brackish water, but these specimens do not necessarily imply that the Wilcox shales are of that character, since the bones may have been accumulated at the mouths of rivers or adjacent to the shores. However, some of the present Crocodilidæ are denizens of salt water, and it is not at all improbable that various extinct broad-faced species may have had similar habits. The turtle bones accompanying the remains are massive and heavy, very different from the typical marine types.

[1] Owen, *British Fossil Reptiles*, Vol. II, Plate XLII, Fig. 2.

In conclusion, from the study of considerable material, and the attentive perusal and consideration of the facts and arguments offered, especially by Koken,[1] I share the opinion of most recent writers on the crocodilia that the separation of the amphicœlian and procœlian crocodiles by Huxley, which at one time seemed so brilliant a generalization, into the suborders Mesosuchia and Eusuchia is unnatural and artificial. I believe that the change from amphicœlous to procœlous vertebræ has been concurrent in two, possibly in all three, of the modern types of Crocodilia, the Gavialidæ, Tomistomidæ, and Crocodilidæ. In the specimens from the Hailey shales the centra may best be described as cœloplatyan, the anterior concavity deep, the posterior one shallow, if any. The change from this form to a distinctly procœlous one is not at all difficult to understand, and was brought about, I believe, by the same or similar causes in the different phyla. The true teleosaurs could not have been ancestral to any of the modern crocodiles, since the marked difference in the size of the fore and hind limbs was a specialization for aquatic habits, as was carried to a greater degree in the Thalattosuchia,[2] and could not have reverted to the more modern amphibious type, even that of the gavials. That the true crocodiles began existence as terrestrial, or at least terrestro-amphib-

FIG. 3.—*Coelosuchus reedii.* Proximal extremity of right humerus, one-half natural size.

[1] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 105; *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 767.

[2] Fraas, *Paleontographica*, Vol. XLIX (1902), p. 1.

ious, animals is scarcely open to doubt, and all are agreed that the phytosaurs were not this ancestral type. That they should have become more aquatic in habit than are any now living, and again reverted to a subterrestrial habit, as in the modern alligators, is difficult, if not impossible, to believe. The true teleosaurs, like the thalattosaurs, were a short-lived branch of which no modern descendants have survived. Owen has thought[1] that the introduction and development of the small mammals was a cause of the evolution of the small, brevirostrate crocodiles, the Atoposauridæ and Goniopholididæ; but I doubt this very much, though they may have been the inciting cause of the evolution of such diminutive forms as *Alligatorellus* and *Atoposaurus*. Were more extensive land faunæ to be discovered in the middle and lower Jura, I believe that we should find the remains of real amphibious brachystomous crocodiles, much less like the structure of *Teleosaurus* than is *Teleidosaurus* even. It is hard to believe that the littoral reptiles, or semiaquatic forms, like *Pleurosaurus*, *Acrosaurus*, etc.,

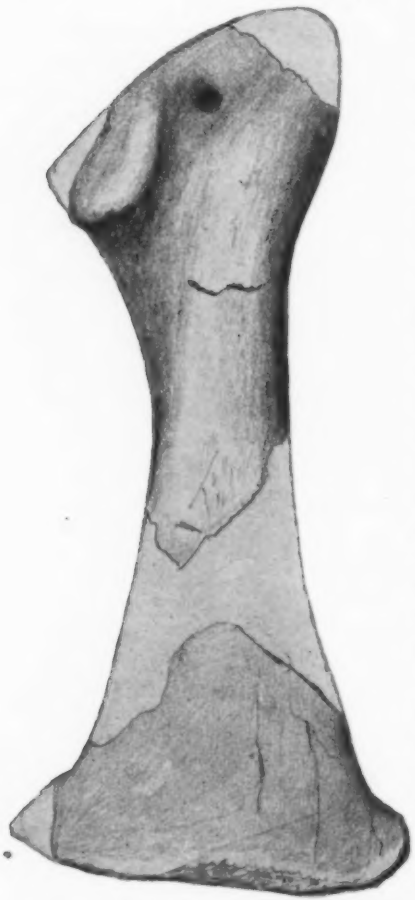
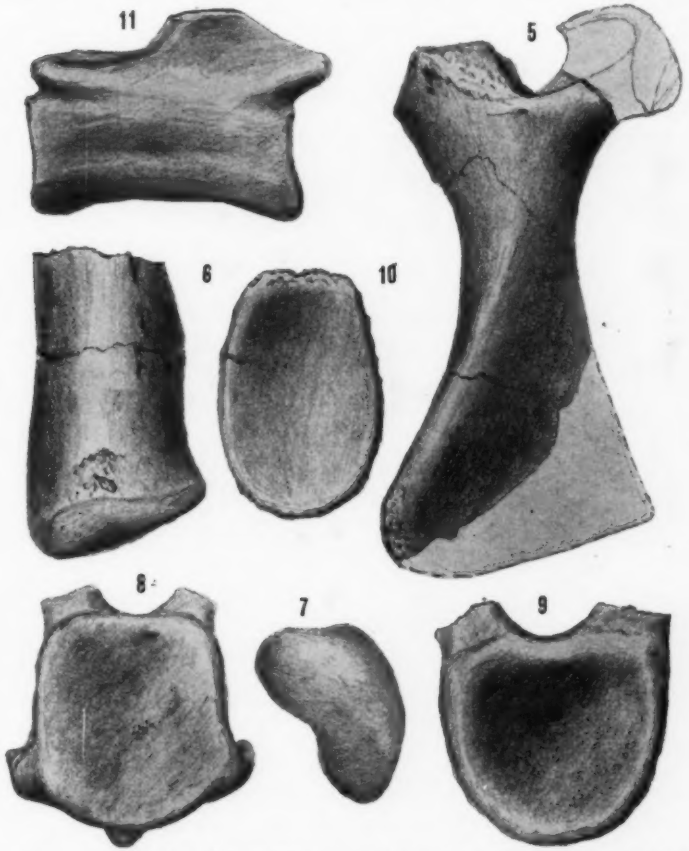


FIG. 4.—*Coelosuchus reedii*. Right coracoid, one-half natural size.

[1] Owen, *Quarterly Journal of the Geological Society*, February, 1879, p. 148.

of late Triassic and Jurassic times, were not as legitimate objects of prey for the amphibious crocodiles as were the small mammals.



FIGS. 5–11.—*Coelosuchus reedii.* All two-thirds natural size. Fig. 5, left ischium, Fig. 6, distal extremity of left tibia; Fig. 7, distal face of same; Fig. 8, proximal face of cervical vertebra; Fig. 9, proximal face of dorsal vertebra; Fig. 10, proximal face of dorsal vertebra; Fig. 11, caudal vertebra.

The terrestrial and amphibious crocodiles, with short, broad heads, are yet to be discovered in the Triassic rocks, probably as low as the Muschelkalk.

Just what has been the cause in each case of the change from amphicœlous to procœlous or opisthocœlous vertebræ may not be apparent, but it is no more difficult to believe that this change occurred in the different phyla of crocodiles than in the different orders of reptiles. We know that all procœlian reptiles cannot be traced back to a common procœlian ancestry. The earliest verte-

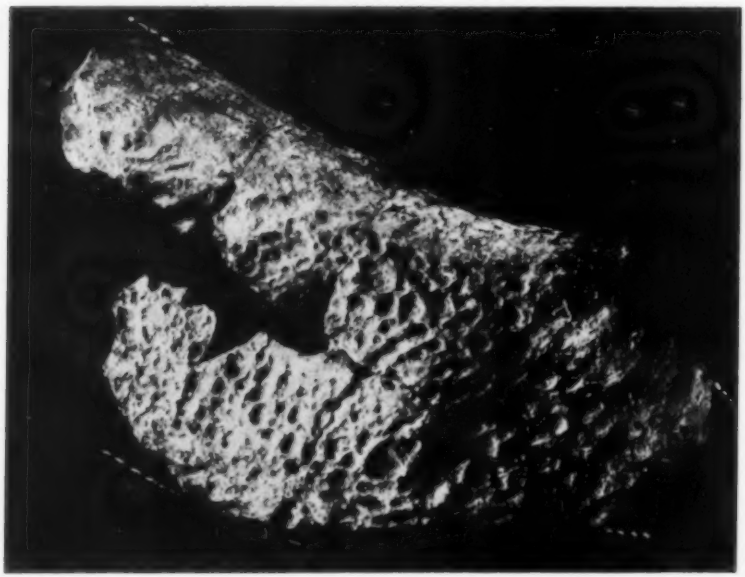


FIG. 12.—*Coelosuchus reedii.* Posterior portion of left mandible, one-eighth natural size.

bræ of this type were apparently those of the Rhaetic or Liassic pterodactyls. Many of the squamata had changed from amphicœlian to procœlian by the close of the Jurassic times, and it is not at all improbable that the beginning of the change in the crocodiles occurred about this time; certainly so, if the vertebræ described by Seeley from the Wealden are really those of crocodiles, as seems probable.

The geckos among the lizards, chiefly climbing or pendent animals in habit, have retained amphicœlous vertebræ, long after

their loss by terrestrial lizards—a fact which does not render their separation from other lacertilia into a distinct suborder imperative. Toads, the most terrestrial of all amphibia probably, have procœlous vertebræ.

The procœlous structure has never been attained by either aquatic or highly amphibious forms; on the contrary, the amphicœlous structure has persisted longest in such. Its attainment has always been correlated with the use of the hind limbs in the support or propulsion of the body upon land, and the amphicœlous structure has lingered longest in the tails, as in the dinosaurs and pterodactyls. The ichthyosaurs, with feeble hind limbs, retained a very primitive structure of the vertebræ, till late in Cretaceous times, until nearly all other reptiles had acquired convexo-concave vertebræ; while the plesiosaurs, equally aquatic animals, and doubtless derived from nearly as primitive ancestors, acquired in many cases truly amphiplatyan vertebræ—a fact doubtless to be correlated with the important use of the hind legs and a well-developed sacrum. The procœlous vertebræ of the mosasaurs was a character acquired by their ancestral terrestrial forbears, as was also their scaled skin. A consideration of these facts, together with the pterygoidal inclusion of the posterior nares, serving no apparently useful purpose in such purely ichthyophagous reptiles, inclines me to the belief that the modern gavials are late descendants of the more terrestrial procœlian types such as *Thoracosaurus* or *Holops* may have been. The opisthocœlous type of vertebra is of much wider distribution, and has been acquired by purely aquatic animals such as *Lepidosteus* and the true salamanders.

No form of convexo-concave vertebræ is of profound morphological significance in the evolution of the vertebrates, but I would not go quite so far as does Koken in uniting procœlian and amphicœlian crocodiles in the same family, notwithstanding the extraordinary resemblance of other parts of the skeleton.[1]

[1] Koken, *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 768.

GLACIAL EROSION IN THE FINGER LAKE REGION OF CENTRAL NEW YORK[1]

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The origin of the Finger Lake valleys was assigned by Lincoln[2] and by the present writer[3] to glacial erosion upon the evidence of hanging valleys, though this name was not then used. Later recognition of other evidence, notably the steepened lower valley slopes, the smooth, straight valley walls, and the absence of projecting spurs, characteristic of regions of marked glacial erosion, supported this explanation. When, however, quarrying operations revealed an area north of Ithaca in which pre-Wisconsin decay was preserved on the steepened slope of Cayuga valley, it seemed necessary to reconsider the question of the origin of this valley. In a paper presenting the newly discovered facts[4] the general question of the origin of the Finger Lake valleys was reconsidered and three hypotheses were proposed as working hypotheses. No attempt was made to establish either of the hypotheses, but the object of the paper, avowedly an unfinished study, was to show that the problem was less simple than formerly believed, and that there were objections to the glacial-erosion theory of sufficient force to warrant a question whether some other theory than glacial erosion might not account for these valleys. The fact that I have been quoted as an opponent of the glacial-erosion theory for these valleys, which has not been the case, is the reason for this preliminary statement.

One of the three hypotheses considered in my previous paper was stated in the following words:

> A modification of the glacial-erosion theory has been advanced during the progress of the investigation of the problem, and is still being considered. It is as follows: During its first advance the ice deeply eroded the valleys; during

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *American Journal of Science*, Vol. XLIV (1892), pp. 290–301.

[3] *Bulletin of the Geological Society of America*, Vol. V (1894), pp. 339–56.

[4] *American Geologist*, Vol. XXXIII (1904), pp. 271–91.

interglacial conditions the older gorges were cut; with return of glaciation the valleys were deepened still further. During as many glaciations as this region experienced this process was continued. On this basis the older gorges are interglacial; their cause is the lowering of their base level by the overdeepening of the valleys to which they were tributary. Since facts sufficient to establish or to overthrow this explanation are not yet at hand, it must stand at present merely as a working hypothesis. [1]

Work done since the publication of this paper strongly supports the theory of double glacial origin for at least the Seneca valley. In this valley there is a general condition of remarkably perfect, broad, mature tributary valleys hanging several hundred feet above the lake level, at about the 900-foot contour. They are truncated by the straight, smooth, lower steepened slope of the main valley, so that they stand out prominently, with open mouths, clearly discordant with the main valley, and about 1,500 feet above the rock floor of the Seneca valley at Watkins.

These hanging valleys are trenched in their bottoms by gorges partly buried in Wisconsin drift. The buried gorges are both broader and deeper than those of postglacial origin. Along the western shore of Seneca Lake from Watkins to the northern edge of the Watkins topographic sheet, a distance of eight miles, there is absolutely continuous rock, proving that the gorges have not cut below lake-level. Yet the rock-floor of the main valley is 1,000 feet below lake-level at Watkins. The gorges are therefore also hanging valleys, and a double period of glacial erosion is indicated, with an intermediate condition of interglacial stream erosion.

On the eastern side of the Seneca valley the evidence is almost as clear, though there are some short gaps in the rock-wall. In the Cayuga valley there are gaps in the rock which may possibly be on the sites of the buried gorges, so that the evidence from this valley is not convincing.

In my previous paper it was pointed out that there is a marked discordance in the hanging valley levels of neighboring valleys, and this fact was then considered to be evidence opposing the glacial-erosion theory. Both Salmon and Six Mile Creek valleys hang at a much lower level than their neighbors (for example, Fall, Cascadilla, and Buttermilk (Ten Mile)). I am now convinced that the interpretation that this discordance is opposed in the glacial-erosion

[1] *Ibid.*, p. 284.

theory was incorrect, and that these two valleys are really confirmatory of the glacial-erosion theory. This change of view is the result of a recent study of the valley profiles and a mapping of the moranic deposits of the valleys in question. The latter show that these valleys were occupied by actively moving ice parallel to their axes, while the neighboring higher hanging valleys were not. They were therefore open to ice-scouring. A study of the profiles shows that these discordant hanging valleys have the U-shape of glacial erosion and not the gorge-shape of a rejuvenated valley, the only other explanation that seems a possible one for such discordance. It is believed, therefore, that while the Cayuga valley was profoundly deepened by ice-erosion, the Salmon and Six Mile Creek valleys were deepened moderately, and the Fall, Cascadilla, Buttermilk, and other valleys practically not at all, since they were not occupied by ice freely moving along their axes.

There still remains some evidence opposing glacial erosion by the Wisconsin ice-sheet, but none opposing erosion by an earlier advance, unless the fact that no deposits of an earlier ice-advance are found in this region is considered opposing evidence. The most serious objection to Wisconsin ice-erosion is the presence of residually decayed rock at the Portland quarry north of Ithaca. But in view of the striking topographic evidence of ice-erosion of a double period—the condition of double hanging valleys, the steepened slope, the spurless valley wall, and the undissected valley sides—the question may fairly be asked whether even this evidence from residual decay remnant, in a single place, may not be misleading. In seeking for an explanation of the presence of this decay product in the particular place where it occurs, I have found but one hypothesis that appears possible. The Portland quarry lies just south of the junction of Cayuga Lake and Salmon Creek valleys, down both of which the ice flowed somewhat freely. It is possible that the thrust from the Salmon Creek valley pushed the ice toward the west side of the Cayuga valley, leaving the site of the Portland quarry under a wedge of ice with slight motion, and hence with slight erosive power. Too little is known about the erosive action of ice, and the direction of ice-currents under the guidance of topographic irregularities, to warrant further consideration of this question, at present.

To account for the facts briefly outlined in this paper by rejuvenation seems utterly impossible. This hypothesis will not explain the hanging gorges, nor the discordant U-shaped hanging valleys. Formation of the lake valleys entirely by Wisconsin ice-erosion is also out of the question. But the striking resemblance of the topography to that of regions of known ice-erosion seems to demand origin by glacial erosion; and, in spite of the opposing evidence from a remnant of residual decay, and of other objections of less importance, it is believed that such an origin must be assigned to these valleys, and that the apparent objection to such origin is dependent upon some local condition which permitted residually decayed rock to remain, while elsewhere in the valleys there was profound ice-erosion.

THE ICE-FLOOD HYPOTHESIS OF THE NEW ZEALAND SOUND BASINS

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INTRODUCTION

The author feels confident that the glacial explanation of the striking geographic forms in the southwestern Alps of New Zealand finds readier acceptance among those students who, until such time as they themselves have conducted careful and detailed physiographic examinations, have not so much as seen a region of former or present intense glaciation, than with those who have spent their lives amid such ice-modified surroundings. Only to such workers does the whole series of novel perceptions presented during a first glimpse at a formerly strongly glaciated region come with the startling force of a revelation. The foregoing is applicable to the case of the author, and because of it he feels warranted in presenting this glacial explanation for certain New Zealand forms. For several years prior to visiting Alpine New Zealand in the summers of 1901 and 1902, he had made numerous topographical observations in Australian New England, Monaro, The Darling Downs, northern Queensland, and Fiji. Between the latitudes embracing these localities, viz., 15° and 37° S., thousands of tributary water-courses had been inspected. All were observed to join the main river channels with non-conflicting, or but triflingly conflicting, grades. The magnificent plateaus of eastern Australia still, in great measure—when composed of felsites and acid granites—retain their individuality as to their central portions, and here, naturally, as they are traced headward, the rivers are observed to leave the wide and well-matured valleys of the uplands in gigantic waterfalls for rapidly trenching canyons. But even at this *initial* stage of canyon growth, with one or two exceptions, easily explicable by local rock variations, etc., the legions of side gulches, although insignificant in length, come in "at grade." Thence, follow-

ing the canyons in their intricate windings to the points where stream corrasion has destroyed the individuality of the plateau, one finds a ceaseless repetition of contracted waterways, tortuous channels, and myriads of overlapping spurs. Above all, the absence of lakes and the wonderful constancy of the "graded" water-courses were marked features.

The first sight of the New Zealand fiords and the Alpine lakes was marvelously contrasted to Australian scenic types, where glaciation had had no part in determining the valley contours. Here (in New Zealand) were great rock basins, broad flat-bottomed valleys, with bordering walls rectilinearly disposed as to their bases, and of even dip, but of such steepness as to be inaccessible to any but daring climbers; a marked absence of spurs; and an arrangement of such valley buttresses that they appeared shriveled up to the canyon walls, their terminations ending in tremendous precipices, the bases of the same being usually in alignment. Here also one saw *lines of sentinelling domes* rising thousands of feet into the air—a prevalence of rock monuments suggestive of sitting lions—and numerous deep and fairly broad-bottomed canyons connecting with the sounds and larger valleys over gigantic walls flush with the main rectilinear ramparts. These remarkable side valleys, seen from below, appeared to spring direct through U-shaped notches in the vertical walls. In the crystalline schists these walls were at times almost monotonously majestic in their steepness and evenness of slope, as in Milford, while in the softer schists of Wakatipu the valleys were broader, the slopes less, and the "hanging valleys" a minor feature. Then again there were the gigantic moraines of the lakes; and, perhaps most striking of all, the wondrous *cirques* or amphitheaters, thousands of feet in height, which, in the denser rocks, almost prohibit the scaling of divides.

No one form just enumerated found a response in the stream-developed contours of the eastern Australian cordillera. The fact was, moreover, well established that this fiord and lake land had been demonstrated, by many workers, to have been one of former intense glaciation, and as such an attempt was made by the writer to furnish a glacial solution to the problem. While still puzzling over the "hanging valleys," Professor W. M. Davis' note on glacial

forms in Norway, Switzerland, and England came under my notice, and, with minor modifications only (as will be seen in this note), appeared competent to explain the New Zealand forms. Later, Dr. G. K. Gilbert and Willard D. Johnson, of the United State Geological Survey, kindly forwarded copies to me of their notes on *cirques* and allied phenomena in northwestern America.

After the publication of the Dunedin note, the importance of the ice-flood hypothesis as explaining the *peculiar* "sound" shapes and the *present inactivity* of glaciers forced itself upon me. The present note is the result.

I desire here to mention the great help derived from a perusal of some of the glacial reports written by Professors T. C. Chamberlin, R. D. Salisbury, W. M. Davis, T. W. E. David, and James Geikie, Dr. G. K. Gilbert, Professor J. W. Gregory, Sir James Hector, Professor F. W. Hutton, Von Haast, Willard D. Johnson, Dr. Lendenfeld, F. C. Matthes, and Professor I. C. Russell. To a great deal of the literature no access has been obtainable.[1]

THESIS

The Great Ice Age marked a flood in glacial action, while the present warm conditions obtaining in these areas of former intense ice-action marks a glacial drought.

The sounds, lakes, and canyons of southwestern New Zealand were determined, for the greater part, by preglacial streams whose channels had attained to the graded stage.

During the height of the ice-flood the glaciers gouged out deep basins much below the baselevel at points near the convergence of profound canyons. Here also they ripped off spurs, aligned and even undermined the walls, thus producing double canyon-cliff slopes.

At other points, such as "broads" and other quiet spots in the preglacial canyons, the ice-scouring was not pronounced. Also at all points away from the central channels aggradation and minor scouring would be noticeable.

Recession of the ice-flood brought about obliteration of former deep groovings in the rock basins and canyon walls, aggradation was almost suspended in the later drought stages, and overriding of old

[1] Since writing the above, I have received a glacial note supplied to the *Journa of Geology* for 1905, by Professor Albrecht Penck.

moraines and general ice-stagnation resulted, inasmuch as the old flood-scoured channels were now too broad and of too slight a grade to admit of further corrasion by the present insignificant representatives of the former glaciers.

CHARACTERISTIC TOPOGRAPHIC FEATURES OF SOUTH-WESTERN NEW ZEALAND

1. *Plateau remnants.*—Around Milford Sound, Lake Te Anan, and Lake Wakatipu there exist numerous sub-horizontal masses

FIG. 1.—Clinton Gorge, showing dismantled plateau, spurless chasm, and wide canyon floor. In the foreground to the right lies a large *cirque*.

(Fig. 1), and long ridges attaining heights of from 5,000 to 6,000 feet. Above these again rise peaks and masses to heights of 10,000 feet. Farther south sub-horizontal masses of much less elevation are encountered (Fig. 2).

These are apparently survivals of a flexed surface, the upland itself representing the advanced maturity of subaerial erosion (in pre-Tertiary times), when the land was at a much lower elevation.

2. *Hanging valleys.*—These remarkable topographical features are most pronounced in the dense crystallines of Milford Sound, while in the softer Paleozoic schists of Wakatipu they are reduced almost to insignificance. They possess fairly evenly graded channel slopes almost to their point of discharge into the main stream. This they join either in cascade form or as sheer waterfalls as much as 2,000 feet in height. In the crystallines the wall which holds the notching hanging valley is generally possessed of a rectilinear base, the preci-

FIG. 2.—Preservation Inlet. Dismantled plateau at much lower level than that in Fig. 1. Also wide valleys.

pice which borders the sounds or canyons at these points being continuous across the inter-hanging valley mouths. This gives a most remarkable appearance as contrasted with typically stream-developed areas (Fig. 3). Magnificent examples of these hanging valleys are the Sinbad Valley (Fig. 4), the Stirling Falls (Fig. 3), and Bowen Falls (Fig. 5).

3. *Rectilinear cliff bases.*—These forms are found in the Hollyford and Clinton canyons, but are even more pronounced in Milford Sound (Fig. 6), and the side valleys of the Cleddau, Arthur, and

Harrison Cove streams. The mountains composing the sides of the valleys of the Wakatipu and Milford Sound types, may be notched and broken by deep ravines reaching down to the water's edge; they may appear even as isolated *bee-hive* and *sitting-lion* shapes; yet their immense bases almost uniformly preserve a wonderful alignment.

4. *Truncation of spurs.*—All stages in apparent truncation of

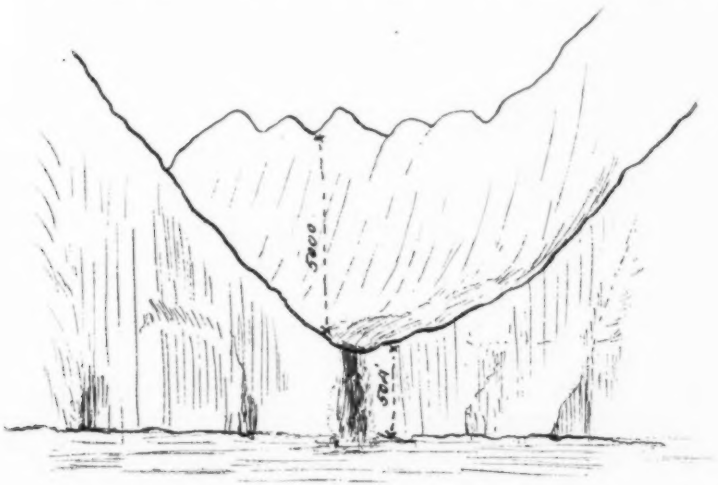

FIG. 3.—Sketch of Sterling Falls, 504 feet high. (From a photo.) Note the alignment of the canyon walls, and the steepness and evenness of the hanging valley walls.

spurs may be found in the sounds and side canyons. The idea suggested from a study of these forms is that of a former series of overlapping spurs which have been subjected to some mighty force, whose maximum strength had been exerted along the lower and central valley channels, causing the planing off of spur ends in some cases, and utter shriveling up of spurs against the canyon walls in others. The more complete truncation of spurs would, of course, result in more perfect alignment of cliff bases.

Examples of these progressive stages in apparent spur truncation are shown by Figs. 7, 8, 9, and 6.

Sitting-lion forms and great bee-hives or domes are also the expression of this apparent mutilation of once long rambling spurs.

5. *Double cliff slopes.*—A feature characteristic of the dense crystallines of Milford and its side canyons especially. Along the bordering walls of these canyons the lower portion is often observed to be absolutely perpendicular for as much as from 1,000 to 2,500 feet. Above these rise the characteristically even, but very steep,

FIG. 4.—Mitre Peak (5,600 feet) and Sinbad Valley. Milford Sound. Note the inaccessible walls of the hanging valley (Sinbad).

rock slopes (Figs. 11 and 12), for other 3,000 feet. Usually the sides rise for some 4,000 or 5,000 feet in this steep fashion (slope about 50° to 60°), but in many places these tremendous lower perpendicular slopes come in. Just below the points of convergence of two steep and deep canyons the feature is much emphasized. Figs. 9, 10, 11, and 12 illustrate the point.

CONTOURS OF SOUNDS AND LAKES

Associated with these double slopes of Milford are found deep rock basins having fairly flat bottoms and almost perpendicular

sides (Fig. 12). These features are also accentuated just below points of deep canyon convergence. The central portions of these rock basins are the deepest, and sounding lines 1,700 feet in length have been employed without reaching bottom.

Generally the sound entrances are *much* shallower and narrower than portions much higher up-stream.

PREGLACIAL HISTORY

The plateau which survives now as ridges and mesas from Lake Wakatipu to Preservation Inlet probably marks the old-age stage of erosion of a surface originating in the Mesozoic folding[1] of southern New Zealand. Differential elevation then ensued, which carried the plainlike surface (developed near sea-level) of the closing cycle of erosion to considerable heights. The early Tertiary sedimentation was probably induced by this deformation. Canyons early became the expression of the cutting action of the streams on the raised area, and during Eocene times a series of anastomosing and graded water-courses were developed in the area. Subsidence ensued, closing the Eocene erosion, the valleys were deeply drowned, and thick masses of Oligocene age were deposited on the Eocene valley floors. This has, it seems to me, been admirably demonstrated by Hutton,[2] in his reply to Von Haast's[3] assertion that the canyons of the New Zealand Alps are due entirely to ice-action; for, according to Hutton, Oligocene limestones occur on the lower slopes of Lake Wakatipu, this same valley having been carved out of the schists by streams in Eocene times on the uplifted plain. Therefore, taking Lake Wakatipu as a type of these lakes and fiords, we are driven to the conclusion that deep valleys had been carved in the hard Paleozoic complex by Eocene streams, and that on subsidence ensuing at the close of that period, the lower valleys were drowned and Oligocene limestones deposited.

Afterward elevation ensued, and the forces of subaerial erosion once more came into play. Now, if stream-erosion here was com-

[1] F. W. Hutton, *The Geology of Otago.*

[2] *The Geology of Otago*, pp. 86–94. This volume is a real treasure-house of general geological knowledge for southwestern New Zealand.

[3] *Geology of Canterbury and Westland*, pp. 177–92.

parable to that obtaining on the neighboring Australian continent, then a whole host of overlapping spurs must have characterized the headward growth of the canyons. One, however, looks for them in vain. The plunging waterfalls one expects to see are absent from

FIG. 5.—The Bowen Falls, 550 feet high. A hanging valley in Milford Sound Note the evenly steep walls of the valley.

their heads, being found perched along the canyon *sides* instead, while enormous and almost inaccessible *cirques* represent the initial stages in canyon growth.

The great glacial epoch has come and gone, and with its passing the resurrected topographic forms are seen to be totally different

from forms which we know to be developed by streams in *non-glaciated* areas.[1]

Here, then, is strongly suggested a glacial origin for these forms. In the succeeding pages an explanation of these geographic features is attempted.

FIG. 6.—The northern wall of Milford Sound. Note the alignment (and double slope) of walls at Stirling Falls; also the "hanging" valley to the extreme left.

THEORETIC CONSIDERATIONS

It is here proposed to explain the peculiar topography of the southwestern New Zealand sounds, lakes, and canyons as the result of great ice-floods working along lines of preglacial drainage, developed to late youth or early maturity in lofty plateaus having rapid fall to baselevel (generally sea-surface), and to show that the present glaciers must necessarily, from analogy with ordinary stream-action, be practically stagnant.

The similarity between ice- and stream-action need not be at all

[1] Similarly for the like features of the once strongly glaciated fiord regions of Alaska, Norway, and Patagonia.

strained in this connection. It is only necessary to assume that ice acts somewhat as a viscous body; i. e., that its surface should show a gradually curving fall from summit to baselevel. Thus we get increased velocity with increased volume of ice, as with ordinary streams, and the capacity for work exhibited by the more quickly moving mass is not related by a simple ratio to that performed by the more slowly moving one.

FIG. 7.—Wet Jacket Arm. Note the partial truncation of spurs resulting in precipitous facets facing the Sound.

The same idea of wonderfully increased efficiency as regards cutting, transportation, etc., is seen also during the convergence of two ice-masses into a canyon of very little greater width than either of the two feeders.

TOPOGRAPHIC CONDITIONS OBTAINING IN SOUTHWESTERN NEW ZEALAND

1. We have a much dismantled plateau in the area under consideration (Figs. 1, 2, and 7). Great convergence of these plateau remnant valleys to the later canyons is often observable.

2. The channel bottoms of the incising canyons show *gentle* grades almost to the very heads of the valleys; huge rock basins also exist, the floors of which are frequently lower than the valley bottoms, and are at times far below base- or sea-level itself.

3. Convergence of steep canyons is pronounced, and often marked by the association of huge rock basins, straightened and often per-

FIG. 8.—Crooked Arm. More advanced stage of spur truncation than in Fig. 7.

pendicular lower canyon walls (Figs. 5, 6, and 9), surmounted by steep, even slopes.

4. An immense precipitation is shown for this area, the average probably exceeding 150 inches per annum.

5. Whatever the nature of the agency which imposed these peculiar topographic features on the landscape, the recency of the same and the character of the rocks acted upon have permitted of no alteration in their general appearance.

The problem under discussion is a physiographic one, inasmuch as it deals with the origin of present-day surface contours.

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ACTION OF FLOODS ALONG MATURELY DEVELOPED STREAM CHANNELS

The maturely developed stream channel is composed of reaches of alluvial flats, alternating with graded rocky slopes. These alluvial stretches may be regarded as fleeting baselevels. In periods of ordinary water the stream accomplishes very little cutting or transporting, its energy being absorbed in establishing a perfect adjustment of channel grade, which has been temporarily upset by a freshet

FIG. 9.—The Arthur River at its entrance to Milford Sound. Note the double cliff slope of Sheerdown Hill to the right. See also in this connection Fig. 11.

or flood. Consider now the effect of a great flood on this graded channel. Along certain points of the channel—notably where convergence of streams occurs—deep holes are scooped out below the temporary baselevels. In many cases, along the lower stream courses, basins are formed whose floors lie considerably below their grand baselevel (generally the sea-surface). Every physiographer is aware of such facts. Excavation of banks also keeps pace with this scooping action. Nevertheless, on the other side of the stream aggradation is proceeding hand in hand with this corrasion. The

flood waters which at times surmount the stream banks and spread over the surrounding country are for the most part observed to be stagnant and to form "back-water" masses, in which some aggradation goes on. If some previous channel or natural valley is found by this trespassing mass, a considerable amount of corrosion may occur even at these higher points. This is, of course, in the broads of the stream. In the narrows there is little chance for back water, except in sheltered corners opposite the cutting curve.

FIG. 10.—Lower Milford Sound. Note the immense double slope on the left.

All this is, of course, quite natural. However high the flood, however much it overflows its banks, we expect the maximum strength to occur at or near the central channel portion, while away from the drainage channels we expect aggradation and even stagnation.

With the recession of the mighty flood, we do not expect a continuation of basin excavation below baselevel. On the contrary, we look for aggradation at these points until the normal stream-channel slope has been restored. Nor do we expect the drought-stricken stream to rouse to action the huge loads of flood bowlders littering its channel, and with them to tear away the sides and bottom, even

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as in times of heavy water they struck each other and the containing banks wildly until their shrieks could be distinguished above the roar of the escaping waters. On the contrary, we expect the reduced stream to gurgle *among* the flood bowlders, to override the banks of débris, or to become stagnant even in the depressions. Thus the recession of high water is seen to act in the direction of obliterating the marks made by storm waters.

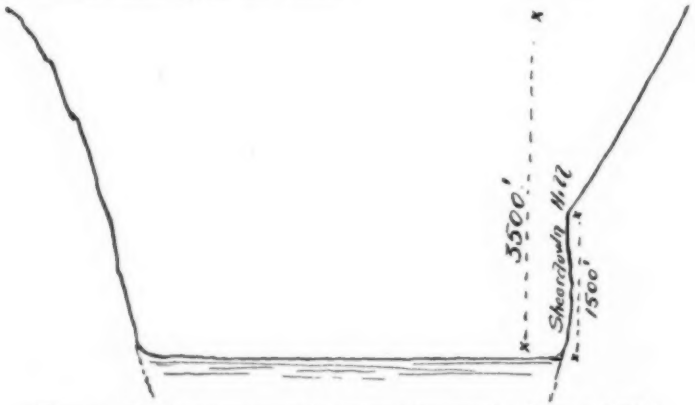

FIG. 11.—Sketch section across the Arthur River mouth. (From a photo.)

Again, in proportion to the advanced degree of stream reduction attained in any region, so are the flood forms just enumerated less and less accentuated in areas of hard, solid structures.

APPLICATION TO ICE-STREAMS

If now the writer has succeeded in stating his case for stream-action clearly, the far-reaching effects of its application to glacial studies must be apparent at once. For it is indisputable that the recent Ice Age marked a glacial flood, while the present insignificant glacial representatives of that momentous period indicate a pronounced ice-drought.

Let us review briefly the probable action of glaciers in these preglacial stream-developed canyons of southwestern New Zealand. As a type of a valley developed by stream-action to the stage of late youth or early maturity, the accompanying sketch of Moonan Brook

(Fig.13) (in New England, New South Wales), may suffice. Here a valley some 3,000 feet deep is seen, many overlapping spurs being noticeable.

We will suppose that convergence of plateau remnants to heads of canyons, as also of these deep valleys into each other, is a common feature.

With the increase in ice-volume, the valley becomes gradually

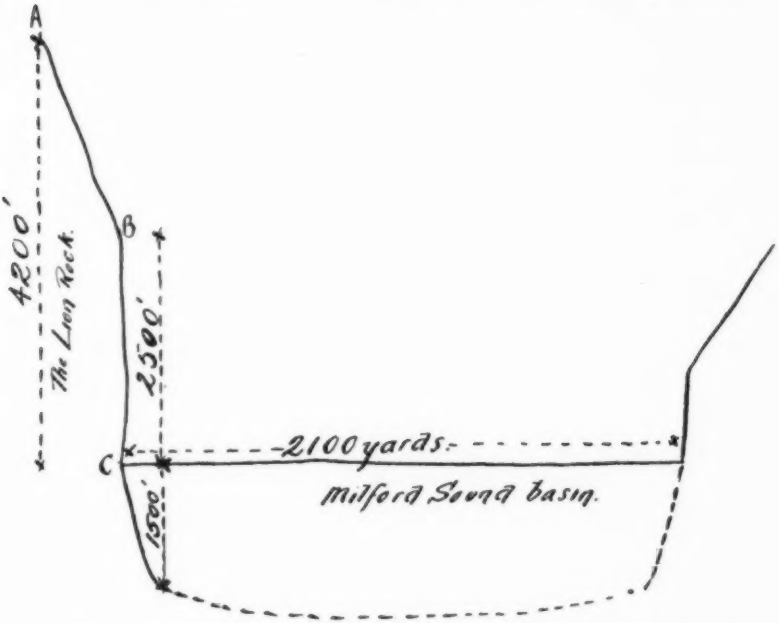

FIG. 12.—Sketch section across Milford Sound. (From a photo.) To the left are seen the effects of the heavy ice-thrusts just below the convergence of Arthur, Cleddau, and Harrison Cove streams. Fifty yards from its cliff, the Sound is 1,500 feet deep.

filled with a glacier. With increased volume or convergence (the confluent ice-surfaces will generally keep at same level) comes added velocity. The directions of flow have been determined for it and its tributaries by the preglacial streams, and the lines of maximum depth and motion will be along the portions vertically above the old stream channels. Even should the glaciers fill the valleys, the higher

they rise above the canyon rims, the stronger the resultant thrusts along the central channel, as in the case of ordinary stream floods. Along the lower spur ends the maximum force will thus be early expended. The upper portions of the spurs will experience great wear and tear, but the amount will be trifling as compared with that felt by the spur portions near the base of the central channel. The rock load, as also bottom friction, will cause reduction of speed along the *lowest* portions of the glaciers, and, as with streams, we

FIG. 13.—Sketch of Moonan Brook (New England, New South Wales). A typical stream-developed valley. Note the overlapping spurs, the spur-cutting and aggradation by floods. Canyon about 3,000 feet deep.

would expect the maximum velocity to occur along the central channel at some point intermediate between the surface and base of the moving ice-mass. Under the tremendous scouring action of the armed glacier, we would then expect the lower spur ends to suffer first. Fig. 7 appears to illustrate this stage of planation. Here the floating spur ends have vanished, and precipitous facets to the sound are presented by the truncated masses.

All this time the glacier is increasing its load, and, as with streams, the strong cutting action may have to be suspended (during local slackness in ice-supply) until the excess of load has been removed. Also as with streams, the degree of spur planation will depend upon their arrangement and development. Small spurs in the direct line of flow will early suffer complete removal, while large ones, favorably situated as regards their preservation (points opposite the cut-

ting curves) will show truncation on certain sides only. Fig. 8 illustrates this well. As the ice gathers strength, it will possibly surmount the great canyon walls, and actually flow over the old, flexed upland. This stage may be considered the period of maximum ice-flooding. After the almost complete truncation of spurs in softer rocks, slopes of moderate batter will be induced in the canyon sides, as they will be too weak to resist the lateral thrusts

FIG. 14.—Sutherland Falls, 1,904 feet high, from a hanging valley which is mature and 2,500 to 3,000 feet deep. Upper Arthur River. Note the majestic wall and notch through which stream comes. Here two deep valleys converge to form Arthur River.

from the swiftly moving glacier. Deep holes will also be plowed in the bottom rocks to great depths below local baselevels. But in the narrower canyons of the dense crystallines, as around Milford Sound, especially where the steep canyons are from 5,000 to 6,000 feet deep, and where marked convergence of valleys occurs, the results will be marvelous. The resultant ice-velocity is much increased as the converging masses are forced into a deep valley only slightly broader than either of its tributaries. The spurs are ripped off, but the resulting massive and aligned walls present great

resistance to the mighty ice-flood. The differential strength of the converging glaciers in their upper and lower parts will be pronounced. Undermining action will set in. The upper portions will be slowly worn back to steep, even slopes, but the cliff bases will experience such tremendous lateral thrusts that perpendicular and even overhanging slopes will be produced at points somewhat lower than halfway down the valley sides. The disposition of the converging valleys will indicate which side of the lower canyon is selected for special attack. In exceptional cases[1] bottom thrusts will also, near these points of canyon convergence, excavate rock basins possibly several thousands of feet in depth below baselevel.

Figs. 6, 9, and 10 illustrate these stages in wall and bottom excavation in the narrow crystallines.

With the *undermining* action by the heavy lateral thrusts of the lower portions of the glacier, the lower ends of many weaker tributary valleys will be shorn off, and their mouths will be left hanging along the aligned cliff bases.

Figs. 5, 6, 11, 12, and 14 illustrate these points well. The diagrams are taken from photos of Milford and the Arthur River. No one, we venture to say, could see lower Milford Sound and fail to see in it a *heavy* ice-flood working along lines of preglacial drainage.

As might have been expected, the northern wall of Milford has been selected for special attack. This is well seen just below the junction of the Arthur and Cleddau canyons, but the point is still further accentuated a little farther down, where the immense glacier of Harrison Cove was picked up. The great corrasion of the eastern wall of Harrison Cove is also noticeable as compared with that of its western one.

Beyond these points come the evidence of minor spur truncation only, the contracted sound entrances, and the shallowing of fiord waters. As we might have expected, the huge rock basins and associated "hanging valleys," double cliff slopes, etc., are seen in places like this where the ice-fall is pronounced. Beyond this plunge to baselevel we should expect comparative stagnation.[2]

[1] The depths attained will be a measure of the thickness of the ice-sheet.

[2] From considerations of lack of gathering ground for ice, the cessation of corrasive power after fall to baselevel, etc.

But even in periods of maximum ice-flood many broads or divergences in the channels (canyons) would form spots where aggradation or partial glacial stagnation would occur. The deep fiord basins, with their associated lower precipices, steep, even upper slopes, aligned cliff bases, and "hanging" valleys, mark points of maximum ice-scour, and occur in exactly the positions where we would expect to find them; but there are other spots at which we would expect to have evidence of much less efficiency of ice-corrasion. This is even so. At these points spurs are not observed shriveled up to their containing walls, nor are rock basins found. These points correspond with the smoother waters of a stream-flood. In the canyons themselves these evidences of weakened erosive power may occur only at some *considerable height above the channel bases.*

Again, as the ice-flood in places welled over the canyon sides after the manner of a river overflowing its banks, so we could expect very little comparative scouring to occur at these points. There will be no natural drainage lines to follow at this level, and the ice-overflow will here expend most of its energy in opposing gravity as it rises above the upland irregularities. Aggradation with pronounced stagnation results from this. *Old* drainage lines may, of course, be found, and here, especially on declines,[1] ice-corrasion may be considerable; or the ice-cap may open onto the steep sea-front and set up incipient valley formation here. "Hanging" or even graded valleys may result thus, if the ice-flood be of considerable duration in time.

Consider now the effect of diminishing the ice-supply. Decrease of volume is marked by loss of speed, and this by a *wonderfully* decreased capacity for work. Long before ice-drought conditions shall have set in *active* corrasion will be suspended, and *aggradation* will be the order of the day. For during the period of flood the channel bases have been graded so as to be adjusted[2] to the heavy burdens passing over them. Now an ordinary stream[3] is wholly

[1] The writer would insist on the idea being kept in mind that a glacier should corrade more on a *decline* than on an *incline.*

[2] A stream-flood may occupy several days only, while the glacial period (summation of ice-floods) probably lasted very many thousands of years.

[3] We should say this law applied to viscous substances generally.

or mainly functional in readjusting the grade along which a *mighty flood only* could do effective work. Until such time, aggradation at the majority of points will ensue. Thus it is with our retreating ice-stream. The deeply scored channel, the huge rock basins (between widely separated canyon precipices adorned with "hanging" valleys), marked the grade along which the ice during a maximum flood *only* could accomplish work. The least retreat of the flood would cause cessation of cutting at these points. Although the canyon ice-overflow might be stopped, yet the canyon itself might be full. Nevertheless, cutting work would be ceased along these points of maximum excavation, since pressure and speed have been reduced in the central channels. The only work the glaciers can now accomplish along the rock basins will be the partial, or at times even complete, obliteration of the deep grooves which marked their high-flood attack. Hence we should expect the rock basins to lose their deep chisel marks, and slight scratches,[1] or even smooth surfaces, to be substituted as the power of scouring became progressively feebler. Huge loads of rubbish could still be carried, and these would be dumped just below the rock-basin mouths. With still farther ice-retreat the loads would be dumped into the lower ends of the rock basins (lakes and sounds). Hence would arise great shallowing up at the sound entrances. With farther recession the glaciers would be unable to even *move* their former bottom loads, and then would ensue the overriding of moraines (formerly the tools with which the glacier accomplished its work). Still later stages would be marked by stagnant or inactive glaciers. Thus arise, in the author's opinion, the inactive glaciers of Alaskan, Norwegian, Alpine, and other canyon bases. They are enormous ice-masses, it is true, but the fact must not be lost sight of that they are but the veriest pigmies as compared with their colossal representatives during the Ice Flood. Still again, the channel grades existent at present were formed *during the flood*, and as such the channels of today at these localities are too wide, and possessed of slopes too much reduced, for corrasion to be noticeable in the present ice-drought stage.

[1] The declines of the troughs would be more scoured in these later stages than the lower inclined floors. Nevertheless, in the Ice Period these were more deeply chiseled.

Therefore we should expect readjustment of *grades* at present. So far is this distant in point of time that the deep rock basins are still only partially filled up. Until such readjustment of stream grades be brought about, *aggradation and stagnation* with local minor corrasion will be the only expression of present-day ice-action.

In comparing these "facts of form" in New Zealand with those of other strongly glaciated regions *in areas of steep profound canyons having short runs to baselevel*,[1] such as Alaska, Norway,[2] and Patagonia(?), we are struck with the wonderful similarity between the several topographies. In all are found the same tremendous fiord depths, the steep bordering walls, the peculiarly shaped rock basins, the truncation of spurs, the wealth of domes, the magnificence of the *cirques*, and the prevalence of "hanging" valleys. In all is observable the evidence of a former widespread intense glaciation. The steep-walled canyons possess their peculiar features in the most marked degree near the points of convergence. In no formerly non-glaciated region are such features obtainable; indeed, non-glaciated New Zealand and Australia stand out in the most marked contrast. It has also, in the previous pages, been shown that, on the assumption of an ice-flood—a fact which cannot be disputed—the observed forms are precisely those which could be expected. If New Zealand forms are explicable on the hypothesis of stream canyons modified by ice-floods, so also are those of Alaskan, Norwegian, Alpine, Sierran, and similar localities.

A couple of other points might be touched on at this stage, the remainder being reserved for treatment when considering the objections raised by several leading geologists to the theory of profound ice-modification.

1. Subsidence has often been advanced to explain the depth of fiord waters. Against this the writer[3] would strongly protest, unless supported by observation. It is utterly opposed to the evidence yielded by a study of *recent* New Zealand and eastern Australian

[1] I. e., great comparative velocity by steepness of ice-fall, convergence of canyons, etc.

[2] The Californian Sierras, the Rockies, and the European Alps doubtless fall also into line with these localities.

[3] For New Zealand.

topography. Subsidence postdating glacial times there has certainly been in New Zealand and Australia, but apparently to nothing approaching the depths required to sink these old ice-channel floors 2,000 feet or more below the sea-surface.

Furthermore, the fact of the striking depths found in the Norwegian, Alaskan, and Patagonian fiords, and the strong contrasts presented thus with associated non-intensely glaciated areas, are very suggestive.

Rock-basin excavation along old stream channels below base-level during periods of maximum ice-floods combined with *slight* later drowning is a sufficient explanation.

2. *Cirques* also appear explicable on the assumption of ice-sapping,[1] and find their counterparts in stream-action in rock basins excavated by the undermining action of water falls.

The magnificence of the glacial features (lakes, sound basins, cliff slopes, *cirques*, etc.), as compared with the holes, bank-cuttings, and flood-heaps formed by water, is due to the fact that in the case of the one the corrading agent was confined to a trifling portion only of the valley, while in the case of the other the glacier occupied the whole of its valley.

ANSWERS TO OBJECTIONS

In H. L. Fairchild's recent glacial note[2] a great number of hitherto unanswered objections to glaciation as an efficient corrader are advanced. To most of these the ice-flood hypothesis furnishes a satisfactory answer.

Thus (p. 19) Fairchild adduces the frequent presence of rock-polishing and slight ice scratches only instead of "deep groovings and cornice-like flutings" as evidence against the efficiency of ice-erosion.

Now, these smooth surfaces, slight scratches, and general absence

[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904); also Dr. G. K. Gilbert, "Systematic Asymmetry of Crest Lines in the High Sierra of California," *ibid.* Since writing the above, Professor Albrecht Penck has sent the author a paper on "Glacial Features in the Surface of the Alps," *ibid.*, Vol. XIII, No. 1 (1905). In this remarkable paper the author sees additional confirmation of his "ice-flood" hypothesis.

[2] "Ice Erosion Theory a Fallacy," *Bulletin of the Geological Society of America*, Vol. XVI, pp. 13–74, Plates 12–23.

of deep groovings are exactly what we should expect to find on the hypothesis of a former glacial flood and present ice-drought. For the old channel was adjusted to its ice-flood load; the ice-recession was gradual, and work now, instead of being directed toward deepening flood basins, was confined to weaker dragging of loads and minor cutting. In these processes the deep flutings, etc., must to a great extent disappear.

(P. 20) With regard to flexibility of glaciers: Water cannot hold its load stiffly up to its work; yet the observations of the author along New England (New South Wales) stream tracks prove that water can hold bowlders up so effectively that marvelous demolition of spurs and channel bottoms is soon brought about.

With regard to many roche moutonnée forms, we should look upon them as tending to produce stagnation in a viscous mass away from the main drainage lines. We should also, as with water, expect to see far more work done on the downfall side of a rock mass than on its inclined side.

(P. 21 [4]) The analogy need not be carried beyond granting apparent viscosity and flow for glaciers. It does not here concern us what causes the motion. What we feel sure of is: Increased volume gives added velocity, and with flowing masses this gives wonderfully increased efficiency of transportation and corrasion.

Page 21 (5) does not carry weight, in the face of the fact that the present Muir glacier is indisputably a drought-glacier stagnating in its old *broad and more than baseleveled* valley.

(Pp. 22, 23 [7 and 8]) These objections are answered later.

(P. 26) Fairchild claims that rapid corrasion by ice is a self-checking process. If one watches a stream, he will see all the stages of bank-cutting, aggrading, and load-shifting in progress at the same time. Streams, either of ice or of water (or any viscous matter whatever), must adjust themselves to their burdens. If a flood is on, the stream will cut vigorously in one place and aggrade in another. With diminution in volume, transportation sets in until the excess of load is removed. Yet all the time the material is surely being carried to the grand baselevel. This is the way the glacial saw clears itself for cutting.

(P. 27) In areas removed from the centers of drainage lines ice

must override obstacles, even as the back waters of a high flood must. Corrasion is here reduced to a minimum, for the simple reason that these areas are not situated along graded channels.

The overriding of drumlins by ice-masses is what must be expected *at any stage* succeeding to the *high floods* which produced them. The drumlins are analogous to the great masses of débris piled up along the banks or along the channels of a stream during high flood. With the recession of the flood the load is dropped, and the babbling brooklets of subsequent dry phases must either trickle through or override the débris. But as for water, so for ice, the drumlins owe their existence to former floods.

(P. 27) "Could not a very deep glacier, having great pressure on its bed, along with a steep gradient, giving high velocity, rapidly abrade its bed?" Fairchild says "No!" But why not? It is only *along* these old preglacial lines, whether belonging to the newer canyon stage or to the older valleys of the flexed upland remnants converging into the canyons, that we claim such erosive power. We do not even need steep channel grades. A sharp convergence of two canyon glaciers into one very little larger in cross-section, especially if the walls are strong and deep, will furnish the velocity needed to give the increased efficiency of erosion needed.

But, as before remarked, over the bulk of the area—i. e., in inter-stream channel areas—we do not expect much cutting work to be done.

(P. 28) Fairchild states that basin excavation is less probable than valley-widening. We maintain that in New Zealand sounds the evident aim of the glaciers *is* to widen and flatten their floors. At certain points of convergence, however, especially when the high and strong walls are confined, the thrusts find partial expression during high floods in basin excavation the while undermining operations are going on. (See *ante*, also diagrams and photographs.) We are thoroughly acquainted in New Zealand with the tendency to widen valleys by ice.

(P. 31) These points have all been answered in other parts of the report on the ice-flood hypothesis. Similarly the peculiar basins of the Sierras, Cascades, Alaska, Norway, and New Zealand have been shown to result from ice-floods along channels of *profound* preglacial canyons, especially just below points of canyon convergence.

Of course, in an area of preglacial drainage carried to late maturity or early old age, especially in areas of gentle or moderate relief only, we would expect comparatively little action to be manifest even during the height of the ice-flood. This point should always be kept in mind by anyone comparing such widely varying regions as England, the Canadian plains, or Norway.

Where the stream-flood dashes its load angrily along the torrent tracks of a youthfully dissected plateau, there should we expect to see the vigorous thrusts of converging canyon glaciers. Now, Alaska, Norway, New Zealand, and Patagonia (?) are countries having young profound canyons intrenched in high plateaus. New England and many other places appear to have had their preglacial drainage well advanced. Apart, then, from certain minor features in their canyoned plateaus, we should expect to see evidence only of comparatively sluggish glaciers. This also applies to Fairchild's criticism on p. 33.

(Pp. 34, 35) Greenland has passed through its ice-flood phase as well as other regions, and therefore *its glaciers should now be stagnant as compared with their ice-flood representatives.* The *main* work was accomplished along the centers of the preglacial drainage lines, and the swarming of the ice-cap over areas of irregular hills and hollows is analogous to the "backing-up" action of ordinary flood waters against obstacles. During the height of the flood the grades of the old drainage were altered to meet the requirements of the heavy ice-cap. Now, of course, heavy as the ice-masses are, they are hopelessly incompetent to the task of corrading these old channels.

Even during the maximum ice onslaughts the ice in inter-stream areas could only corrade strongly if it discovered (or formed) a drainage line. Otherwise it would simply override hills and aggrade here and there.

(Pp. 37, 38) Referring to Professor A. C. Lawson's description of the Kern Valley, we venture to suggest that the previous notes explain these features.

(Pp. 39, 40) Without having seen Lake Chelan, we venture to suggest that it may be analogous to certain apparently non-strongly glaciated valley portions in New Zealand. Yet this is to be expected,

since some portions of a stream bed are preserved, while others are deeply corraded during flood stages. But in every instance in the New Zealand fiord region where lake basins, etc., occur, we could have predicted the same from the peculiar conformation of the associated canyon structures. Lake Chelan should be studied with this in view.

(P. 41) To the objections raised on this page it can only be again said that ice-action in infantile, youthful, mature, and other phases of plateau-dissection must not be confounded.

(P. 42) This present condition of the Muir and other glaciers is what *must* result on the assumption of a former efficient ice-flood. The glaciers are now in their drought stages, and lack all capacity for corrasion along their old *basined* channels.

(Pp. 42–46) Fairchild, in criticising Dr. Gilbert's report, apparently considers that physiographers claim the *general* deepening of fiords, etc., to the extent of thousands of feet. Now, in New Zealand, these rock basins, although immense, are yet only a portion of the canyon lengths, and mark the points of convergence of deep canyons. Along the upper canyons for many miles the floor may be flat or exist as a series of terraces.[1]

Thus Wakatipu arises from convergence of the Dart and Rees canyons; Milford Sound arises from convergence of the Arthur and Cleddau valleys; while these valleys themselves are fairly flat, and their bases are probably nearly 2,000 feet above the lake and sound floors.

With respect to the differential erosion *along the fiords* (i. e., preglacial drainage *channels*), and on Annette Island, it must always be remembered that, as a rule, *in the converging narrows the streams scour, while on the associated broads they aggrade.*

As for the view, held possibly by some, that the fiords are wholly the product of ice-scour, all the physiographic evidence in New Zealand points to the fact that the ice-action was confined to working fiercely along the central drainage lines, with production of *local* spurless chasms, rock basins (sounds and lakes), and double wall slopes, alternating with comparative stagnation of glaciers at points where one would expect stream-action to be expended in aggrading.

[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904).

One would thus naturally expect to get islets remaining after the glacial flood occupation of a wide fiord, since this is the *stagnant* divergent, as opposed to the *rock-basining* convergent, canyon stage.

SUMMARY

The problem is a physiographic one, since it deals with the origin of present-day rock contours. It is analogous to the study of stream channel and bank contours.

Southwestern New Zealand was in pre-Tertiary time dissected by subaerial agencies to the early old-age stage.

In early Tertiary(?) time this so-developed surface was flexed, attaining a height of about 6,000 feet in the northern portions. Massive residuals of this plateau attained heights of 10,000 feet above sea-level.

During preglacial times the canyons of this area were determined by stream-action. The channels of these water-courses possessed harmonizing grades.

Their present contours are the result of marked modification by ice-action during the period of maximum glaciation.

The Great Ice Age marked a flood in ice-action, while the present much warmer conditions obtaining in formerly intensely glaciated regions are significant of a glacial drought.

The action of this ice-flood is best illustrated by comparing with the stages of an ordinary stream in flood.

In the case of ordinary streams, mighty floods along alluvial flats are frequently observed to *scoop out* holes many feet below these temporary baselevels, especially at points where marked stream convergence occurs. Along either the broads or the bank opposite to that where active cutting is in progress, *aggradation* also occurs during the very height of the flood. With the rising of the stream above its banks, masses of *stagnant back water* also are produced, whose principal function is aggradation as opposed to degradation.

Recession of the flood waters brings about aggradation at the points where maximum excavation was carried on during the flood. Especially does this occur at spots where scooping out *below baselevel* occurred.

Similarly for the ice-streams of the Glacial Period in New Zealand

along the lines of preglacial drainage. Just below the point where two profound canyons junction to form one deep valley, comparable only in width with each of its feeders, the ice-masses converged, and, by analogy with viscous fluids, would thereby have their velocity increased. Thus during the height of the ice-flood, they ripped off spur ends, straightened the canyon walls, finally undermining the sides and *scooping out deep rock basins thousands of feet below base-*(sea-) *level.*

During the height of the glacial phase (flood stage), aggradation would progress hand in hand with canyon lowering and widening. Thus, wherever "narrows" in the canyons opened out into "broads," glacial action—so strong just below the points of canyon convergence—would here receive a decided check. This would also be very noticeable even during the rock-basining stage in the narrows. Again, as in the case of ordinary streams, we should, on this theory of ice-action, expect practical ice-stagnation at the majority of points at distances from the centers of the main drainage lines. Thus ice-masses swarming over the canyon rims, and flooding the stream-dismantled plateau, would find their counterparts, in stream-action, in the "back-water" of a flooded river. It might be, of course, that, in the case of ice, some old, deserted plateau channel might be found along which corrasion could be effected; or it might be that the mass would start corrading some steep sea declivity and form "hanging" valleys, the return of warm conditions checking ice-corrasion at this stage.

After the ice-flood came recession of the glaciers. As with ordinary streams, *aggradation* and *smoothing* (along declivities) now became the work of the ice-drought glaciers.

Along the rock basins, undercut walls, etc., which marked the work accomplished by the ice-flood near and below baselevel, the rapidly diminishing glaciers would be mainly employed in obliterating the traces of their former handiwork.

1. They would partly or wholly efface and smooth over their original deep rock groovings, formed during vigorous ice-thrusts.

2. Smoothing of rocks would later practically cease and aggradation commence.

3. Ice-stagnation or overriding of gravels would finally ensue.

For a little reflection will show—as with ordinary streams—that at these points the valleys are too broad, and their grades have been too reduced, to permit of work other than aggradation.

As with streams, again, so with the retreating glaciers. On the least reduced slopes a little cutting will be still accomplished, but aggradation, moraine-overriding, and general ice-stagnation will now characterize these *old* channel grades which formerly expressed *the slopes in which the glaciers of mighty ice-floods only could effect corrasion.*

Hence, in my opinion, arise the present stagnant, although possibly large, glaciers of regions such as the Alaskan and Norwegian fiords; for along the *old flooded channels* of such localities, before they can again resume cutting, they must readjust their channel grades. Until such time they will be engaged removing excess of load, in filling up of rock basins. Even a slight ice-flood at the present stage would have its operations mostly confined to aggrading.

"Hanging" valleys mark the differential erosion of main and tributary channels during the *height* of the ice-flood. Undermining of canyon walls and truncating of spurs near convergence of narrow valleys would cause recession of tributary graded channels, and at these points one would naturally look for fine examples of "hanging" valleys. A magnificent example for study is afforded by Milford Sound along its northern wall. Here, just below the junction of the Arthur and Cleddau canyons, the "hanging" valleys, double wall slopes, and aligned walls are pronounced. A little lower down, the Harrison Cove canyon comes in, and immediately below this the deep rock basin, actually overhanging lower wall, and magnificent "hanging" valley occur. On the more protected southern side these resultant thrust forms are not nearly so pronounced.

Subsidence as an explanation of the great depths of the southwestern New Zealand sounds is utterly opposed to the evidence yielded by topographic studies in non-glaciated Australia and New Zealand. Rock-basin excavation *below baselevel* by thrusts from convergent ice-masses[1] is a sufficient explanation, and accounts also for the disposition and shapes of all the associated forms.

Cirques arise from ice-sapping action, as with ordinary waterfalls.[2]

[1] Of course, here, as in New Zealand and eastern Australia generally, a post-glacial subsidence to the extent of several hundreds of feet must be admitted.

[2] See also A. Penck, and W. D. Johnson, *ante*.

The magnificent basins, lower cliff slopes, *cirques*, etc., due to ice-action as compared with basins, banks, etc., cut by water, are due to the fact that in the case of the latter the corrading agent occupied an insignificant portion only of the canyon, while in the case of the former the glacier occupied the whole of its valley.

Too great emphasis cannot be laid on the fact that these features are those which might be expected in areas of former high plateaus in which profound canyons had been excavated during *preglacial* times, and in which valleys marked convergence is a characteristic. Such areas as the Alaskan, Norwegian, Patagonian, and New Zealand fiord and canyon regions, the Rockies, the Sierras, the Alps, etc., appear to answer this description. *In these localities occur the forms predicted on the theory of modification by an ice-flood.*

But in areas belonging to the late-maturity or early old age of stream-erosion, also in areas of very unstable structures the resultant forms will be less strongly marked.

The influence of a continental ice-sheet during the ice-flood is not here discussed, the writer not having visited such a region. The resultant forms, however, could be predicted according to the degree of stream development attained in preglacial times, and to the length of time occupied in ice-cutting.

APPENDIX

AN APPEAL TO "GRADING" AS AN EXPLANATION OF THE PRESENT NEW ZEALAND FIORD, LAKE, AND CANYON CONTOURS

It may now be confidently asserted, as shown in the author's earlier reports, that the fiords, lakes, and canyons in New Zealand—as doubtless also those of Alaska, Norway, Patagonia, etc.—were due, in the main, to preglacial stream-action, and have since been profoundly modified by some mighty agent. The problem then reduces itself to: What is the origin of such striking dissimilarity of topographic contours in fiords and typical steam-developed canyons? The present note ascribes "fiord" topography to ice-streams in high flood (i. e., glacial period) flattening their grades, and excavating deep holes at points of marked canyon convergence.

All streams, of whatsoever material composed, seek to approximate to main baselevel as quickly as possible, but in so doing they are com-

pelled to establish channel grades along which to do *efficient* work. This follows immediately from gravitative considerations, and is illustrated by the grades of *all* stream channels as known to the author. The ultimate result of this continual approximation to baselevel is a complete flattening of channel grades. Flattening or lowering of channel grades is directly proportional to the strength of the eroding agent, and is a common fact of observation. A normal stream may possess a certain grade; a flood finds this so steep that it is enabled to reduce the grade locally, and *yet* maintain great efficiency as regards transportation. Thus at certain points, notably those of stream *convergence*, floods excavate holes below local or even *main* baselevel. These holes show *undercutting* of stream banks and reversal of channel grade down-stream. Stream studies show the amount of this excavation below baselevel to be directly *proportional* to the stage of stream development (i. e., steepness of grade) and the strength of flood. Thus a stream 5,000 feet deep working along a young channel would altogether overshadow the work accomplished by a stream 50 feet deep flowing along an excessively broad (i. e., a very flattened grade) valley.

Now, the glacial period was an *ice-flood*, the streams of ice, in the canyons (young channels) of southwestern New Zealand being more than 5,000 feet thick.

The action was evidently that of a viscous stream, there being a continuous slope in the mass from summit to baselevel. Therefore, from gravitative considerations, the ice-floods would find the channel grades of the insignificant preglacial streams so steep that they could induce in them excessive local flattening and *yet* maintain great efficiency of transportation; i. e., their general velocity, as shown by their still steep surface curves above baselevel, would still be considerable. The disparity in volume between ice- and stream-floods, even allowing for loss in velocity of ice, would induce, at certain marked canyon convergences, such flattening of grade as would (by analogy with stream studies in New England, New South Wales) be commensurate even with the *depth of the ice-stream*. Thus would here arise basins thousands of feet deep, showing reversed grades lower down stream; also the undercutting of canyon sides, and alignment of cliff bases.

Upon the retreat of the ice-flood or floods, one would expect—as with ordinary streams—to find the flood grade altogether *too flat* for

either efficient corrasion or transportation. The diminished glaciers would now be compelled to cease corrading at these points of flood scour and aggrade here until a working grade could be set up or another flood return to carry on its work.

Glaciers of the present ice drought should, therefore, lie inactive or stagnant along these flood-holes (i. e., fiord, canyon and lake basins), while overriding of moraines without transportation and aggrading of flood-holes would set in.

Such were among the theoretical conclusions[1] of the author after a preliminary tramp through New Zealand and a comparison with eastern Australian stream channels. This idea suggested the possible existence of "facts of form" unnoticed during the first short excursion to the Sounds, but nevertheless absolutely necessary to the success of the theory.

Opportunity was found later to examine Milford Sound while the idea was framing itself, and the forms sought were found. Thus in the *strong* crystalline schists of the famous fiord, the canyon walls, just below the convergence of the magnificent Cleddau and Arthur valleys, 5,000 feet deep, show steep upper slopes with marked *undercutting* up to great heights above the fiord base, an alignment of walls, absence of spurs, and an enormously deep rock basin. Just here a third and fourth canyon enter the narrow main channel, and the undercutting, with production of hanging valleys cut off by a great *rectilinear* wall, is very pronounced. Nothing could be more suggestive of rock basins excavated by ice-floods at canyon convergences than the old steep lateral channel grades of these "hanging valleys" now separated by vertical cliffs, due to undercutting, from the flattened grade of the main channel. Still lower down no side canyons come in, and the fiord soon shows a decided *reversal* of channel grade.

All this points to the work of a *flood* or of floods during the *youth of glacial attack*. This idea of youthful ice-attack, exemplified by fiord and canyon contours in strongly glaciated regions was first advocated by Professor W. M. Davis.

Subsidence thus appears to be *practically* negligible in forming present fiord depths.

[1] Other deductions made were the necessity for absence of this tremendous excavation at marked canyon *divergences;* and other points noted in main report. All these appeared to be satisfactorily seen at Lake Wakatipu, Preservation Inlet, etc. Dr. G. K. Gilbert's observation of lack of glacial erosion in Annette Island, Alaska, appears to be a case in point.

STRETCHED PEBBLES FROM OCOEE CONGLOMERATE[1]

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Assistant State Geologist

The stretched pebbles here described occur in the vicinity of Ellijay, Gilmer County, Georgia, about seventy-five miles north of Atlanta. They are well exposed in a railroad cut on the Louisville & Nashville Railroad a few hundred yards north of the Ellijay station, and are also to be seen at various points both north and south of this place, along the public highway. They seem to be confined chiefly to a narrow belt less than one-half mile wide and about fifteen miles long, lying immediately west and parallel with the Louisville & Nashville Railroad. There are several other points outside of the belt here named where stretched pebbles are occasionally met with, but at no place do they reach such a remarkable stage of elongation. The region in which the conglomerate pebbles occur forms the western margin of the Crystalline rocks of the state. The surface is hilly and rough, but not so mountainous as farther to the east or west. The prevailing rocks of the region are slate, mica-schist, gneiss, marble, and conglomerate, all much folded and contorted. These rocks belong to Safford's Ocoee Series, a group of rocks of great thickness and of unknown age, but apparently older than the Lower Cambrian rocks lying farther to the west.

The beds of stretched pebbles, which at some places are several in number, vary in thickness from eighteen inches to five feet. They are invariably interbedded with mica-schist, and always dip at a steep angle. The beds differ from one another chiefly in the size of the pebbles of which they are formed, and in the extent of elongation of the individual pebbles themselves. In some instances the pebbles have been only slightly flattened or elongated, while in other cases they have been elongated more than twenty times their

[1] Published by permission of the state geologist.

original diameter. The matrix or binding material, which constitutes only a small percentage of the pebble beds, consists mainly of mica. Where the mica is absent or nearly so, the quartz pebbles are frequently found welded together for the greater part of their length; however, a slight pressure is usually sufficient to break the bond without injury to the individuals. Each of the several pebble beds examined consists of two kinds of pebbles, namely quartz

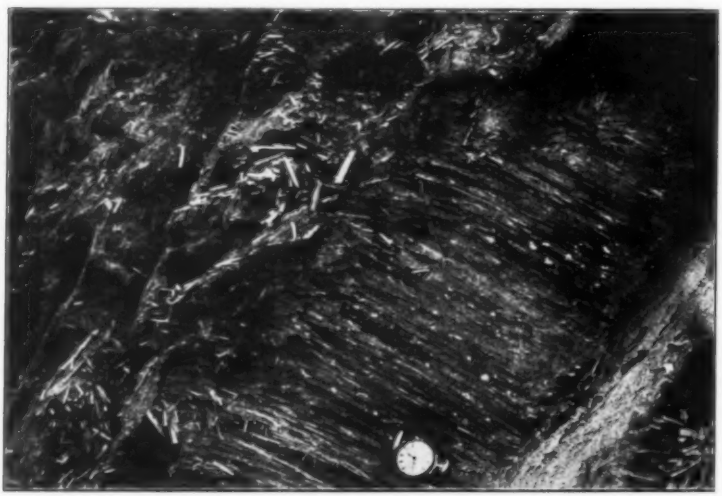

FIG. 1.—Bed of stretched pebbles near Ellijay, Gilmer County, Georgia. White spots show feldspar pebbles not elongated.

pebbles and feldspar pebbles. The former are by far the more abundant and and are always greatly elongated. The feldspar pebbles, on the other hand, are never elongated, but still retain in a more or less perfect degree their original rounded shape. The feldspar pebbles, which are partially kaolinized, are well shown in Fig. 1, where they appear as rounded white spots.

The chemical analysis of one of the pebbles by Doctor Edgar Everhart, chemist to the State Geological Survey, here given, shows it to be orthoclase feldspar:

Soluble silica	3.59
Insoluble silica	59.57
Total silica (SiO_2)	63.16
Alumina (Al_2O_3)	21.04
Ferric oxide (Fe_2O_3)	1.02
Lime (CaO)	none
Magnesia (MgO)	trace
Potash (K_2O)	14.44
Total	100.19

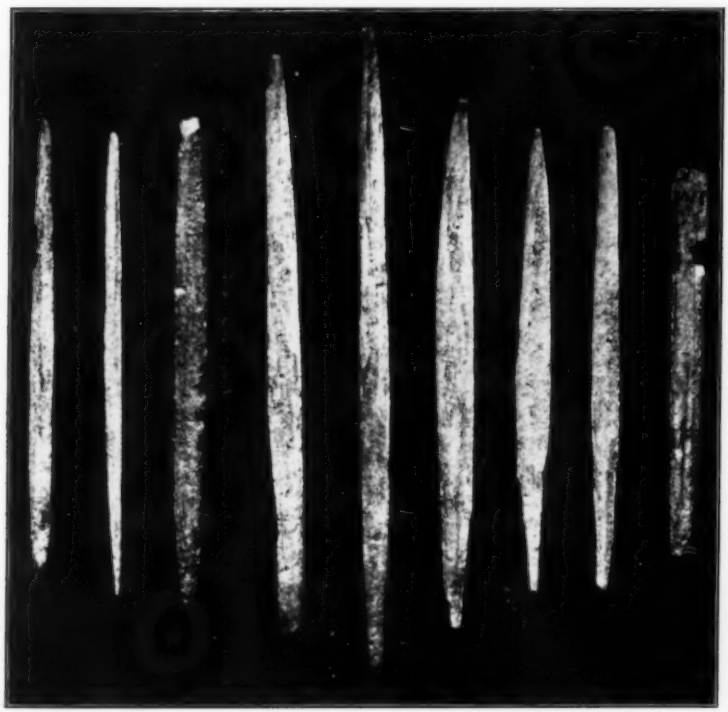

FIG. 2.—Stretched quartz pebbles, three fourths natural size. Pebble at the extreme left has been pierced by a feldspar pebble.

The elongated quartz pebbles are always small, rarely weighing more than a few ounces. Their greatest diameter is generally near the center, from which point they gradually taper to a point at both

ends. In a tranvserse section they are ellipsoidal, with sharp, knife-like edges. Their sides are often striated, and occasionally indented by depressions, or in some cases even pierced by the feldspar pebbles (see Fig. 2). The color, when unstained by foreign material, is that of milky quartz. The texture is granular, and the larger pebbles are slightly elastic. The latter property seems to be most

FIG. 3.—Micro-photograph of transverse section of stretched quartz pebble.

pronounced when the pebbles are first taken from the bed. After drying they become somewhat brittle and have to be handled with more care. The individual pebbles appear to have no cleavage, but break as readily in one direction as another. The following analysis by Doctor Edgar Everhart shows that they are almost pure silica:

Soluble silica	1.29
Insoluble silica	97.84
Total silica (SiO_2)	99.13
Ferric oxidee (Fe_2O_3)	0.77
Alumina (Al_2O_3)	0.16
Total	100.06

Microscopic examination of thin sections of the pebbles shows that they are made up of interlocking quartz granules containing numerous small inclusions. Some of the granules exhibit a banded appearance somewhat like, but different from, plagioclase feldspar. It has been suggested that these bands are possibly due to striæ made by grinding; but this explanation hardly seems plausible, as such irregular surfaces would probably be rendered invisible by the Canada balsam. In sections tranverse to the long axis of the pebbles the granules are elongated; but in sections parallel to the long axis, and in the short axis of the ellipse formed by the cross-section, as well as in sections parallel to the long axis, and in the long axis of the ellipse formed by the transverse section, the elongation of the granules is not so pronounced. The degree of elongation of the individual granules in the tranverse section is about sufficient to account for the flattening of the pebbles in that direction. The mechanical effect of strain or stress shown by wavy extinction was not observed in any of the sections.

PRE-CAMBRIAN NOMENCLATURE

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University of Toronto

The report of the committee of American and Canadian geologists appointed by the surveys of the two countries to compare notes in the field and decide upon a suitable nomenclature for the pre-Cambrian formations of the Upper Lakes, forms an important landmark in the geology of that region. While it is evident from the report itself that the results attained represent a compromise, not perhaps altogether satisfactory to either party, in the long controversy which has been waged over the relationship of these complex and difficult formations, yet it is to be hoped that, at least in its broad lines, the proposed nomenclature will be accepted by future workers in the region, putting an end to the confusion which has reigned. The position and reputation of the members of the committee give their decisions great weight, and doubtless their nomenclature is the best that could be framed to reconcile the two points of view.

Accepting it as such it may still not be amiss to discuss certain features of the report, as they appear to one who has worked over much of the region on the Canadian side.

The brief summing up of the results of their field-work in the various districts visited is of use as showing the ground covered by the committee, and the materials which they brought to bear on the solution of the problems of the pre-Cambrian; and in general their conclusions seem quite justified, in spite of the short time which could be devoted to any one place. Several members of the committee had of course previously done a large amount of work in the critical localities and were thoroughly familiar with the field relationships. It is to be regretted, however, that so few of the characteristic sections of the Rainy Lake region were visited, and that the important Michipicoten district was not visited at all. In the latter case Professors Van Hise and Leith had, however, acquired some first-hand knowledge of the field relations.

The locality visited for a study of the Rainy Lake Couchiching was, however, decidedly unfortunate, since characteristic Couchiching is not displayed at Shoal Lake.

It must be remembered that Lawson's admirable work in the region was devoted to mapping the rocks on a lithological basis, since the time relationships were obscure. Finding a series of sediments distinct from the prevailingly eruptive or pyroclastic rocks which he had previously studied on the Lake-of-the-Woods, he gave them the name Couchiching, and mapped all the sedimentary gneisses and schists under the same color. He considered the Couchiching to be lower than the Keewatin, and in general he was correct in this; but the significance of the conglomerates occurring in various parts of the region was evidently not clear to him. The mica schists which overlie the basal conglomerate at Shoal Lake should really be excluded from the Couchiching, on account of their much later age, though lithologically very like the typical rocks. The greater part of the rocks mapped as Couchiching lie far below the conglomerate, often at the base of the series of schists, through which, as Lawson proved, the granite and gneiss have pushed eruptively, though similar bands occur at higher levels among the Keewatin ash rocks and volcanics. The later schists above the conglomerate clearly belong to the Huronian and not to the Keewatin.

If the committee had examined the region about Rice Bay, a few miles west of Shoal Lake, they would have found a thick series of Couchiching schists and gneisses associated with banded silica and graphitic slate of the iron formation, undoubtedly more ancient than the Shoal Lake conglomerate since the latter incloses many pebbles of the same banded rocks. Similar associations occur at Fair's farm, about two miles west of Fort Frances, where the iron formation is intimately connected with typical Couchiching. A still better example of the same relation is found at various places to the north; for instance, along the Canadian Pacific Railway near Dryden, where an iron range has been traced for several miles, everywhere parallel to and interfolded with characteristic Couchiching schists.

In the American pre-Cambrian regions south of Lake Superior the amount of sedimentary material associated with the Keewatin pyroclastics and eruptives is insignificant, so that, not unnaturally,

the basement complex is looked on by American geologists as overwhelmingly eruptive in origin. This is by no means the case, however, in the Rainy Lake and Wabigoon regions of Ontario, where in some places the Couchiching sediments cover many square miles and are thousands of feet thick.

Logically the basal formation should be called the Couchiching, since our time subdivisions in all later formations are founded on sedimentary rocks, the eruptives being looked on as, in a sense, accidental. Still we may follow the committee in using the pleasant-sounding name Keewatin, which was given first and has been widely used by other writers since Lawson introduced it, in place of the uneuphonious Couchiching.

Turning to another point, the suggestion of the committee that the name Laurentian should preferably be confined to granite and gneiss older than the lower Huronian will not commend itself to many Canadian geologists. As shown by Professor Willmott and the present writer in the Michipicoten and other districts of northern Ontario, this would cut out the majority of the areas of gneiss and granite named and mapped by Logan and his successors as Laurentian. As they are in some cases the actual rocks which received the name from Logan, and as they occupy an enormously greater area than the similar rocks in the United States, one fails to see why the recognition of the later age of most of these granites and gneisses should be so grudgingly allowed. Why should it be permissible only "in certain cases" and "preferably with an explanatory phrase" to call these rocks Laurentian? Should not the usual relationship be accepted as typical, and the explanation be applied to the older granites and gneisses found in the comparatively insignificant basal complex south of the Great Lakes?

This question of the relative age of the Laurentian and the basal sedimentary rocks is evidently rising in other quarters also, as may be seen from Professor Keyes's article on "The Fundamental Complex of the Southern End of the Rocky Mountains,"[1] where he evidently looks on all sedimentary rocks as necessarily later than the Laurentian or Archaean. Now that it has been proved that water-formed sediments, sometimes in large amounts, belong to the basal complex and

[1] *American Geologist*, Vol. XXXVI, No. 2, p. 116.

are older than the Laurentian eruptives in the Great Lakes region, where these rocks have been most widely studied, should not the western geologists revise their point of view and drop either the "Proterozoic" or the "Azoic," or both, from their nomenclature?

A third point in the report requires comment, viz., the separation of the Keweenawan from the Huronian as an upper pre-Cambrian formation. The break between the Keweenawan and the Animikie is certainly not more important than that between the Animikie and the next lower formation, the Middle Huronian of the new classification, Logan's Upper Huronian. If the Animikie, which was not included by Logan in the Huronian, is now placed within it, why not close up the gap and include the Keweenawan also as a provisional fourth division of the Huronian? Probably most geologists who have studied the Keweenawan would be inclined to place it with the Cambrian, and some have suggested that the Animikie also is early Cambrian. Certainly the two formations should go together.

Since the Huronian as mapped by Logan and Murray included some areas now called Keewatin, the new definition has shifted the use of the term upward, omitting part of the lower rocks, but adding the Animikie above. Logan intended that the Huronian of the upper Lakes should include all the rocks between the base of the Cambrian and the Laurentian, since he suggests that the two divisions of the upper copper-bearing rocks (now known as the Animikie and the Keeweenawan) are probably equivalent to the Potsdam and the Chazy.[2]

If the Huronian is defined as including all between the Cambrian and the Keewatin, the term "Algonkian" becomes unnecessary and should be dropped, at least in the Lake Superior region. Possibly its use might be continued in the west, where the equivalence of the pre-Cambrian beds with those of the east is not certainly proved, but the law of priority should undoubtedly reinstate the name Huronian in the east. However, the term Algonkian is carefully omitted from the committee's report, perhaps in order not to raise a fresh subject for controversy. It may be taken for granted, I suppose, that Canadian geologists will continue to use the name Huronian instead of Algonkian; and it is to be hoped that if American geologists prefer to retain

[2] *Geology of Canada*, 1863, p. 86.

in the future the term Algonkian, now so widely in use in their literature, they will explain that in the Lake Superior region it is equivalence to Huronian.

In conclusion, it should be made clear that the writer has no desire to criticise captiously the conclusions arrived at by the committee, but merely wishes that all points should be thoroughly considered before we are finally committed to a nomenclature which presents some marked differences from the one usual in Canada. Perhaps the American members of the committee have conceded to the Canadians as much as could be expected when one considers what an important and powerful organization they represent—the greatest, and in the main the most ably manned, survey in the world.

The committee are certainly to be congratulated on reaching conclusions with which all geologists working in the region can agree, so far as the broad lines are concerned at least—a result which seemed very distant only a few years ago. Their report should do much to aid in the settlement of difficulties in pre-Cambrian geology in other parts of the world, as well as in the region of the Great Lakes.

Editorial

THE ILLINOIS GEOLOGICAL SURVEY

The organization of a new geological survey is always an occasion for congratulations both to the profession at large and to the state which takes up the work. Illinois is the last to assume the burdens and to reach out for the benefits to be derived from such work, and in many particulars the opportunities in this great central state are unique. The present organization is not the first survey which the state has had. In 1857 $3,000 was appropriated for the making of a complete geological survey of the state—a rather small appropriation for so ambitious a program. The next succeeding assembly, recognizing the inadequacy of the funds, appropriated $5,000 annually for geology and $500 annually for topography, and these appropriations continued till 1872, when the new state constitution prohibiting all continuing appropriations went into effect. At that time $2,000 was appropriated for the expenses of the survey for one year, and in 1873 $7,200 for the succeeding biennial term, with a special appropriation of $1,500 for illustrating Volume VI. The Twenty-fifth General Assembly made a special appropriation of $20,000 for the work, and when the survey was abandoned, funds amounting to $4,000 to $5,000 a year were provided for the maintenance of the succeeding State Museum of Natural History.

The first state geologist, Dr. J. G. Norwood, was appointed in 1851 and served six years. The only published result of his work was a study of the lead and fluor-spar mines near Rosiclare, found in Volume I of the survey reports. His successor, Dr. A. H. Worthen, was appointed March 22, 1858, and served until his death in 1888. His name is the one most closely associated with Illinois geology, since he directed and carried out the work of thirty years, resulting in the publication of the eight well-known volumes relating to the geology of the state. The last of these was published after his death by his successor in the curatorship, Dr. Joshua Lindahl, by courtesy state geologist. Dr. Worthen associated with himself, in the early

years of the survey, such well-known men as J. D. Whitney, Henry Englemann, Leo Lesquereaux, F. B. Meek, and J. S. Newberry, and while the personnel of the corps changed somewhat in the course of years, the roll included always well-known and honorable names.

The work of the Worthen survey was largely directed to a study of the general geology and paleontology of the state, and was carried out by counties, the entire state being covered. It resulted in a general geologic map, on the scale of six miles to the inch, and, in addition to the county reports, individual papers on the various formations and groups of fossils. There were, however, no economic reports, as that term is now understood, and when the legislature directly ordered a report on the economic geology of the state, the law was nominally complied with by making a scissors-and-paste compilation from the general volumes and publishing separately three small octavos. In those days the close relations of geology to industry and to technology were not so well understood as now, and geologists considered work on paleontology and pure science more in keeping with the dignity of their profession. The older survey none the less laid broad and deep foundations for future work and very greatly stimulated the development of the mineral resources of the state. When it was discontinued—and field-work seems to have practically stopped in 1872—the curator of the museum took up the work of a bureau of information, and, despite the fact that that office soon became part of the political spoils of the state, this work at least was well done.

Feeling the need of a modern re-study of the state, and particularly the completion of the economic work left by the older organization, the last General Assembly appropriated $25,000 annually for the field-work during the biennial term, and provided for a further draft of $5,000 a year on the printing funds of the state, if necessary. The credit for this move belongs largely and directly to Governor C. S. Deneen who, when the matter was brought to his attention, saw at once its importance and devoted himself to bringing the matter about. The co-operation of many others was of course very important, but the active interest of the state administration was essential, and is significant of the new creed that the best government is the best politics, and that reform means as much doing new things as correcting old abuses; it must be dynamic, not static.

Of the funds of the new survey $10,000 per year is by agreement alloted to topographic mapping in co-operation with the United States Geological Survey, which duplicates this allotment. The remainder is devoted entirely to geology, since Illinois provides separately for the study of its soils, water, natural history, and for engineering experiments. In order to promote close co-operation with these various surveys, the director of the State Geological Survey has his office at Urbana at the university, though the control of the organization is vested in an independent commission. This consists of the governor and the president of the State University *ex officio* and, by appointment, Professor Chamberlin of Chicago. In September this commission met and elected as director Dr. H. Foster Bain, of the United States Geological Survey and formerly, as was true of Dr. Worthen, assistant state geologist of Iowa. The remainder of the corps has not yet been announced, except that it is understood that Professor C. W. Rolfe, who is in charge of the department of ceramics at the State University, is also to be in immediate charge of the investigation of the clay resources. Fieldwork on this has already been begun by Mr. Ross C. Purdy, lately connected with Dr. Edward Orton in his investigation of Ohio clays.

It is understood that for the present the work of the new survey will be centered mainly on the study of coal and clay, but that the broader problems of the geology of the state are to be re-investigated in the light of the advances made in general knowledge and theory in the quarter of a century which has elapsed since the old survey ceased work. In this work, and in its general activities, geologists both in America and elsewhere extend to the new organization best wishes, and to the state of Illinois congratulations upon having provided the means for such work.

R. D. S.

Reviews

The Aftonian Gravels and Their Relations to the Drift Sheets in the Region about Afton Junction and Thayer. By Samuel Calvin. (*Proceedings of the Davenport Academy of Sciences*, Vol. X, 31 pages, 1905.)

In this small brochure Dr. Calvin presents the results of an excellent and much-needed re-study of the type locality for the Aftonian. It will be remembered that, when Chamberlin in 1895 proposed a classification of American glacial deposits, he named one of the important interglacial epochs from certain beds occurring at Afton in southwestern Iowa. These beds were correlated with others in eastern Iowa and in Minnesota, and assigned to the interval between the Iowan and Kansan glacial periods. When the Iowa Geological Survey took up the study of the drift deposits, it was very shortly determined that the lower drift of eastern Iowa was the upper drift of southwestern Iowa, and presumably the one to which the term "Kansan" should be applied. This being so, the beds at Afton must represent a pre-Kansan rather than a post-Kansan period of deposition; and if they were truly interglacial, any drift below them represented an earlier glacial interval than any at that time recognized in the region. Ten years ago, belief in the complexity of the glacial period was not so unanimous as now, and there was some hesitancy in taking so radical a step as was involved in the recognition of an additional glacial advance. In the years which have since passed, the pre-Kansan has been widely recognized, and its existence is now fully established.

In 1898, when the reviewer studied the Aftonian localities, certain of the exposures were obscure, and the evidence was confusing, so that it was thought wiser to make no certain deductions as to the exact relations of the Aftonian to the Kansan. Professor Calvin has been so fortunate as to be able to study new exposures which completely explain the puzzling irregularities noted before, and which leave no doubt of the Aftonian marking a true interglacial interval separating the pre-Kansan from the Kansan by a notable period of time. Mr. Savage had already shown from paleo-botanic evidence[1] that the correlation of the beds at Afton with

[1] *Proceedings of the Iowa Academy of Sciences*, Vol. XI, pp. 103–9.

those at Oelwein in northeastern Iowa was correctly made, so that now there is satisfactory evidence for almost the whole of the story. Whether the pre-Kansan drift is entirely covered by the Kansan, or at some point has a surface development beyond the margin of the latter, is not entirely settled, though the observations of recent years tend to support the view that the pre-Kansan represents only an incomplete advance of the ice and was wholly overridden by the Kansan, representing the maximum advance.

H. FOSTER BAIN.

Economic Geology of the Bingham Mining District, Utah. By JOHN MASON BOUTWELL. With a Section on Areal Geology by ARTHUR KEITH, and an Introduction on General Geology by SAMUEL FRANKLIN EMMONS. (Professional Paper No. 38, U. S. Geological Survey.) Pp. 1–413, 49 plates, 9 figures.

General.—The sedimentary rocks, which are all of the Upper Carboniferous system, consist of 10,000 feet of quartzite containing eight limestone beds aggregating 2,100 feet in thickness. They are cut in many places by intrusive monzonite and younger extrusive andesite. The ores of the region occur in veins cutting all rocks, in beds in the limestone, and disseminated through the monzonite.

Genesis of ores.—The ores may be grouped into three classes: copper ore in monzonite, the lode ores, and copper sulphides in limestone.

1. Copper ore in monzonite.—A relation appears between the amount and quality of the ore, and the degree of alteration of the including rock, suggesting a secondary origin for the ore. Microscopic examination showed the ore to be imbedded in secondary quartz and sericite, proving its secondary origin. The conclusion follows that the copper was deposited from hot solutions in the monzonite after its solidification.

2. The lode ores.—These are confined to fissures. Hot aqueous solutions rose through great northeast-southwest fissures, altered the country rock somewhat, and deposited the lode ores in largest bodies between limestone walls, mostly by filling, but slightly by replacement. The solution was rich in carbon dioxide and sulphur, and a slight solvent of limestone, as shown by the presence of much calcite in connection with the ore, by the great bodies of sulphides deposited, and by the displacement of some of the limestone by the ore. Deposition was aided by decrease in pressure, by the varying slope of the fissures, by contact with limestone, and probably by the material displaced from the limestone.

3. Copper sulphides in limestone.—These ores occur only in fissured regions of limestone marmorized by the contact with monzonite. Inasmuch as it retains the bedded structure of the limestone, and shows every conceivable stage of replacement when observed microscopically, the conclusion is that it was deposited by a molecular replacement of the limestone. The source of the copper was the intrusive monzonite, while the transporting agents were hot solutions or vapors emitted from the intrusives either from the top or from great depths.

The district is a steady producer of low grade ore, and is the foremost camp of Utah in the production of copper. More of the sulphide ores are being found continually, and progress is constantly being made in the production of low-grade copper, which seems likely to prolong the mining activity of the region indefinitely.

The report is clearly written, and betrays systematic and thoroughgoing work. A. C. T.

Geology of the Tonopah Mining District, Nevada. By JOSIAH EDWARD SPURR. (Professional Paper No. 42, U. S. Geological Survey.) Pp. 295, 24 plates, 78 figures.

Ore deposits were discovered in the Tonopah district in April, 1900, by James L. Butler. The geologic structure is complex. The rocks are of volcanic origin, probably Miocene-Pliocene, except for a series of water-laid tuffs. The successive flows have been named earlier andesite, later andesite, five recognized rhyolite-dacite series, the Siebert tuffs, and finally a little basalt. The region has been profoundly faulted. It is concluded that the faulting was initiated chiefly by the intrusion of the dacitic rocks. After the intrusion there was a collapse, a sinking of the various vents. "The still liquid lava, in sinking, dragged down with it adjacent blocks of the intruded rock."

The veins occur principally in the earlier andesite, and do not extend into the over-lying rocks. Less rich veins are found in the later andesite and one of the rhyolite-dacite series. These veins are formed by replacement in fissured zones. Transverse fissures have determined the position of cross-walls and ore shoots by limiting and concentrating the circulation.

The ores contain silver sulphides, silver selenide, gold in an undetermined amount, chalcopyrite, pyrite, some galena and lead, with a gangue of quartz, adularia and some carbonates. Oxidation has occurred to varying depths, but has not reduced the amount of gold and silver.

The earlier andesite has suffered extensive alteration, near the veins to quartz, sericite, and adularia; farther away to calcite and chlorite. The principal work of the altering waters was the formation of the veins. A detailed account of these changes is given, and a study of typical specimens leads to the conclusion that these waters were charged with an excess of silica and probably potash, with gold, silver, antimony, arsenic, copper, lead, zinc, sodium, sulphur, some chlorine and fluorine; but were notably deficient in iron. By comparison and microscopic studies of the later andesite it is concluded that these altering waters were charged with carbonic acid and sulphuretted hydrogen, and contained magnesia, iron and lime.

The composition of the waters indicated above does not seem to correspond to the composition which waters descending through the rock would have had. An eruption of andesite, followed by highly siliceous and potassic waters, deficient in iron, and an eruption of rhyolite followed by waters rich in lime, magnesia, and iron, present an antithesis which may give, according to the author, some clew to the origin of the waters. Two hypotheses of this origin are considered, an atmospheric and a magmatic. The author favors the latter view.

Besides a detailed discussion of the above-mentioned facts, Mr. Spurr has chapters on the descriptive geology of the several mines and prospects; the increase of temperature with depth in the mines, and concludes the report with a comparison of similar ore deposits elsewhere. F. D. M.

Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section. By GEORGE I. ADAMS. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 1–72.)

Tabulated List of Invertebrate Fossils from the Carboniferous Section of Kansas. By GEORGE H. GIRTY. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 73–83.)

Summary of the Fossil Plants Recorded from the Upper Carboniferous and Permian Formations of Kansas. By DAVID WHITE. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 85–117.)

Notes on the Permian Formations of Kansas. By CHARLES S. PROSSER. (*American Geologist*, Vol. XXXVI, 1905, pp. 142–61.)

Several important contributions have been made lately to our knowledge of the much-debated section of the Upper Carboniferous of Kansas.

The standard Carboniferous Section for America may be regarded as the one which is so fully displayed in the Mississippi valley. It is in Kan-

sas that the most complete development of the upper part of the Carboniferous is found. In this locality the Upper Carboniferous limestones and the so-called Permian beds appear in unbroken sequence. It is unnecessary at this time to go into any of the details that have been for so many years the subject of lively debate. Professor Prosser has recently admirably summarized opinions expressed. What has been really needed in all this prolix discussion has been greater attention to critical data. The entire subject has been lately reviewed by Dr. G. I. Adams.

A most succinct and concise account is the recent memoir on the *Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section.* In the main, Mr. Adams records the results of an attempt after extensive and direct work in the field, to rectify the confusion regarding the stratigraphy and the consequent interminable synonomy which has in Kansas arisen unchecked during the last decade. While it would have been very desirable to have had the same careful inquiry extended over Missouri, Iowa, Nebraska and Arkansas, the fact that it was not does not detract from the memoir under consideration. A comparison of the Kansas formations with their representatives of the region lying to the eastward would have proved of great value, and would have removed a considerable part of the synonomy which still remains in the Kansas area.

Not the least noticeable feature of the Adams bulletin is the nearly complete elimination of the classifications and the nomenclatures of Prosser and of Haworth. Whether or not the author has not gone too far along this line remains to be seen. The same question may be asked regarding the work of the pioneers in the Kansas region.

Dr. Adams recognizes, upon lithologic grounds, four main divisions of the Upper Carboniferous of the region. In order to avoid complications in nomenclature of the Carboniferous, he has thought it advisable not to give names to these divisions. There are: (1) lower shales and sandstones; (2) interstratified limestones, shales, and sandstones; (3) limestones interstratified principally with shales; (4) bluish and purplish shales. These four subdivisions are based wholly upon lithologic characters as determined by the writer mentioned. Critical examination of the data upon which he has founded his groupings shows that, although unnamed, they do not differ essentially from those previously recognized by other investigators who have been in the region, and who have based their determinations, not only on lithologic, but upon broad stratigraphic, faunal, and historic grounds.

Adams' main contention is to draw for the major subdivisions of the section lines that are slightly different from those previously recognized.

Data which he presents appear to give results quite diverse from what he manifestly intended. For the major subdivisions they militate strongly against his conclusions rather than support them. Moreover, Girty's elaborate tables showing the detailed vertical ranges of the fossils clearly not only do not strengthen Adams' position, but very greatly weaken it; and, on the other hand, furnish the strongest evidence yet published that the main divisions previously recognized are very nearly the proper ones. For Adams' chief conclusion the introducing of the faunal evidence is very unfortunate.

The relationships of the so-called Permian of Kansas to the Red Beds are of great significance. Mr. Adams states that—

> the distinctions which have thus far been outlined in Kansas do not hold when the rocks are followed southwestward along their strike into the Indian Territory. Approximately along the Arkansas River, or a little south of that stream, the interstratified limestones disappear from the section, and the formations are accordingly shales and sandstones. Moreover, the rocks in the Indian Territory gradually assume a red color in the higher portion of the section, the line of transition to this color being diagonal to the strike. The Red Beds of Kansas belong to this phase.

Regarding the biotic characters Dr. Girty aptly observes that—

> the constituents of the Kansas section consist of alternations of limestone and shale, the latter sometimes containing more or less sandstone. During limestone-making periods invertebrate life was varied and abundant; but few of the mud beds, however, appear to have supported animal life. With some exceptions, therefore, only alternate formations are represented by fossil faunas. The youngest fauna obtained is that of the Marion formation, the Wellington having so far proved devoid of marine fossils. The oldest fauna occurs in the Cherokee shales. It is rather meager, so far as known, but it is probable that numerous additions to our list of species can be obtained at favorable localities. Many of the faunas in the section are large and varied, and while all are not equally extensive, I believe that their uniform excellence is far above the average in sections of equal length.

The value attaching to tables such as the one given depends upon the consideration of several factors. The most important among these appear to be the following:

1. The precision with which the collections are located in the generalized section.
2. The consistent accuracy of the determination of species.
3. The variety and abundance of the formational faunas, and the uniformity maintained in these particulars throughout the section.
4. The completeness with which the faunas are represented in these particulars by the collections.

With all these elements favorable, the sequence of faunas and the range of

species shown by this table should be applicable to a considerable area. Its applicability should, indeed, be limited only by facts of identity of horizon and of basinal boundary.

The tabulation of the species according to their occurrence in the minor formations, some fifty of which are recognized in the 2,000 feet of strata, is essentially a repetition, though perfectly independent, of a similar attempt made a decade ago. It is mainly valuable in substantiating the conclusions arrived at at that time regarding the serial grouping of the various lithologic units of the region.

Mr. White's record of the fossil plants, while necessarily meager, is important as the most complete list of species yet published. It affords many suggestive considerations. The author states that—

> nearly all the specimens here discussed are of Coal Measures (Pennsylvanian) age. But very little plant material from beds of the supposed Permian of Kansas has yet been described. The University of Kansas, in connection with its geological survey of the state, has accumulated more or less fossil plant material in its paleontological collections. This paleobotanical material, which has been sought with especial regard to the Permian problem, is now being studied by Mr. E. H. Sellards, and will probably receive systematic treatment and illustration in one of the proposed volumes of the state university survey. The writer is under obligation to Mr. Sellards and to the university for specimens, particularly of Permian types, submitted for examination or donated to the collections of the United States National Museum. This material, so far as it has anywhere yet been published, is included in this summary; but such species in the material communicated by Mr. Sellards as are new to science or have not previously been discovered in the state obviously could not be included without unfairly anticipating their full description by him and impairing the originality of his publication. Accordingly, in dealing with the supposed Permian flora in particular, which he has been so successful in discovering, all paleontological discussion of the material is here omitted.

The plant remains throw no light on the possible subdivisions of the section; and the whole Lower and Upper Coal Measures are merely said to represent the Allegheny section of Pennsylvania.

Professor Prosser's article on the Permian, while adding nothing new to the subject, is important as affording a connected review of all that has been written on the Kansas Permian beds during the past few years. A considerable portion of the paper is taken up in defending former positions this author has taken. Concerning the retention of certain names the author mentioned, without bringing out any additional reasons, quotes a final rule of the Federal Survey. Without questioning the good taste of such proceeding, or the fact that it adds no weight whatever to a logical conclusion, it is not probable that any organization on the face of

the earth can fix nomenclature until all evidence has been thoroughly sifted.

In discussing the nomenclature of the Upper Carboniferous system, Professor Prosser falls into the same error that he has previously, notwithstanding the fact that his statements have been corrected, and he furthermore does not appear to have yet grasped the points of that contention. However, as these are taken up in another connection, they need not be considered in detail here. If he recognizes, as he states, the uppermost series of the Carboniferous as the Permian, it seems wholly unnecessary to say the least, to enter into a prolix argument as to whether Oklahoman series and Cimmaron series are correctly determined or not. Taking the first-mentioned position, most persons would pass the second over without argument. The fact that the last-named terms are re-argued by him at length would appear to indicate that the author is not so sure, after all, that they are not valid.

As to the dividing line between the Permian and Upper Carboniferous it is stated that—

> it is clearly shown by Beede and Sellards that the Wreford limestone is a conspicuous formation which may be readily followed from southern Nebraska across northern and central Kansas, at least into the southern part of the latter state. This is fortunate in case the Wreford limestone be considered the base of the Permian, because it will afford a marked lithologic break for the line of division between the Permian and the Carboniferous.

Summing up the main features of these papers, it appears (1) that in Kansas there are recognizable in the Carboniferous section, which is more than 2,000 feet thick, four well-defined subdivisions; (2) that the lines of separation of these major members are essentially those which have been located before and generally agreed upon by those who have worked in the Kansas field during the past decade; (3) that the only matter to be now settled is one of nomenclature—the application of simple geographic names to provincial series. There have been a sufficient number of titles already proposed, which cover very closely, if not quite, the subdivisions recognized. The time is ripe to do away with all petty technicalities, and adopt permanent names. This may easily be done even at the risk of modifying somewhat the original meanings; such a course is far more preferable than the proposal of a new set of titles, which in the end are likely to become synonyms.

In the articles mentioned above numerous references are made to the general Carboniferous section and to sections so widely separated as Pennsylvania and New Mexico. Without intervening sections or some

description of them the comparisons are of small use as elucidating Kansas geology. However, it brings up the question of general classification of the American Carboniferous deposits. If we parallel these provincial sections as types—(I) western Texas, and southern New Mexico, (II) eastern Kansas and Missouri and (III) West Virginia and Pennsylvania—we get something of the following arrangement:

	Time-Divisions	Provincial Series		
		I	II	III
Carboniferous	Late	Cimmaron Wanting? Maderan	Cimmaron Oklahoman Wanting?	Permian
	Mid	Manzanon Wanting? Wanting?	Missouran Des Moines Arkansan	Pennsylvanian
	Early	Socorran	Mississippian	(Poconoan?)

On the whole, it seems advisable not to attempt the impossible by stretching any one provincial series over the entire continent. A general continental section based upon the somewhat elastic time divisions is about as far in the present state of our knowledge as exact paralleling can go.

Charles R. Keyes.

Revised Nomenclature of the Geological Formation of Ohio. Bulletin No. 7, Fourth Series, Geological Survey of Ohio; November, 1905. By Charles S. Prosser. Pp. xv+36.

This bulletin is prefaced by the state geologist, Professor Edward Orton, Jr., giving a refreshing account of the Ohio Legislature setting aside a definite appropriation for purely stratigraphic work, realizing that the proper development of economic resources is directly dependent upon the accurate knowledge of the formations and geological structure of the state. Another feature of the introduction is the statement of an excellent method of dealing with the various requests made to the state geologist to undertake local and private investigations, analyses, etc.

The body of the bulletin is a further elaboration by the author of his article in Vol. XI of the *Journal of Geology*, bringing the subject up to date, but which will receive further attention as the work of the Ohio Survey continues. The author gives a table of the old and new classifications of the formations of the state, and in characteristic manner reviews the literature on the subject and adds the results of his own field studies.

Prior to Prosser's work Ohio stood well in the quantity and quality of the work done by its state surveys. However, owing to the intricate nature of many of the formations and the difficulty of properly interpreting them, much remained to be accomplished. Prosser's work has thrown much additional light on these formations, as the tables of formations show. The revised list of formations is as follows: Alluvium and Glacial, Dunkard formation, Monongahela formation, Conemaugh formation, Allegheny formation, Pottsville formation, Maxville limestone, Logan formation, Black Hand formation, Cuyahoga formation, Sunbury shale, Berea grit, Bedford shale, Ohio shale (consisting of the Cleveland shale, the Chagrin formation, and the Huron shale), Olentangy shale, Delaware limestone, Columbus limestone, Monroe formation (consisting of the Lucas Limestone, the Sylvania sandstone, and the Tymochtee member?), "Niagara group" (consisting of the Hillsboro sandstone, the Cedarville limestone, the Springfield limestone, the West Union limestone, and the Osgood beds), Clinton limestone, Belfast bed, Saluda bed (which is regarded as probably forming the upper part of the Richmond), Richmond formation, Eden shale, and Trenton limestone.

The priority, synonomy, correlation, and application of these names are fully discussed in the *Bulletin*. J. W. B.

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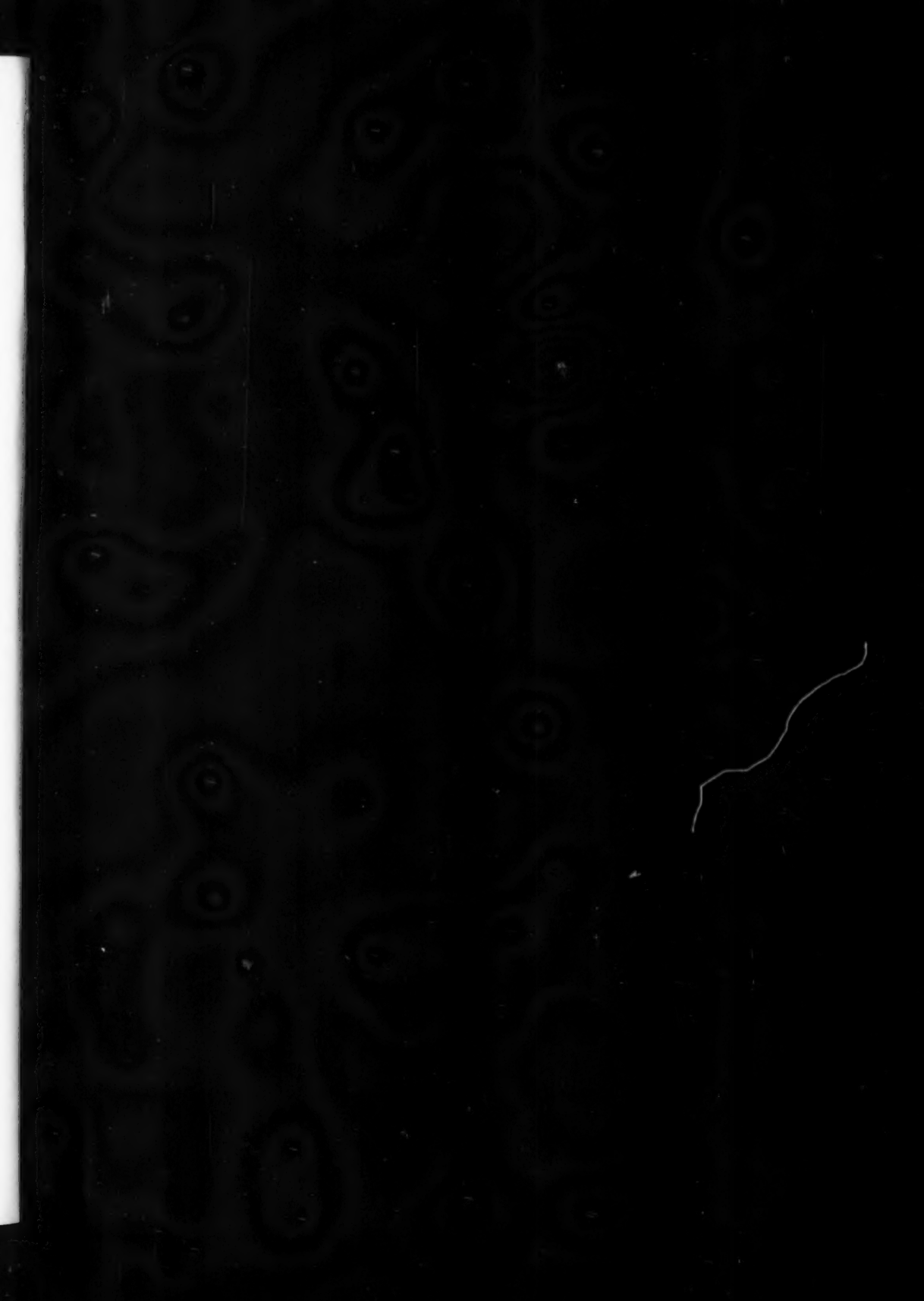
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